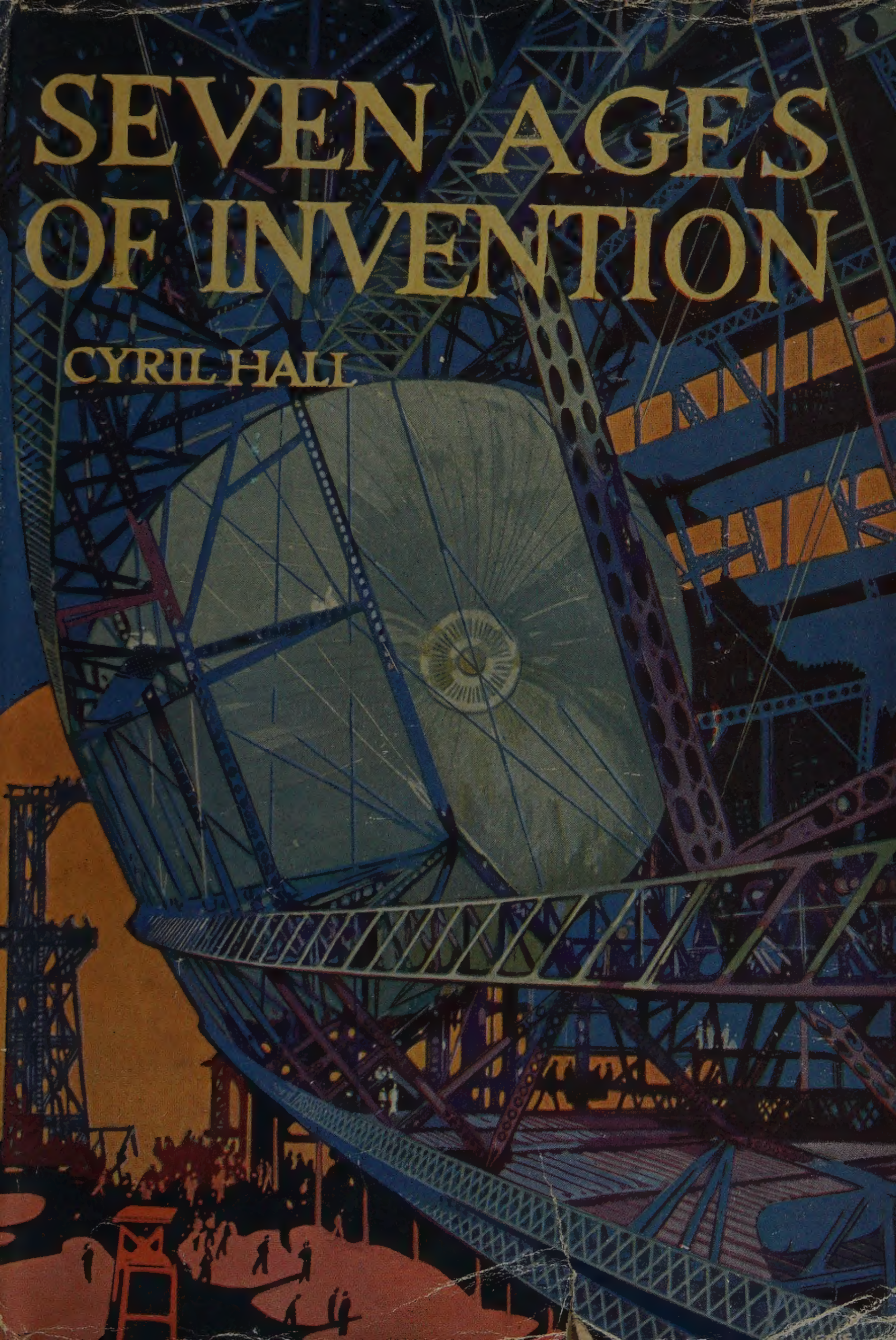
SEVEN AGES
OF INVENTION
CYRIL HALL

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AN AEROPLANE IN FLIGHT OVER LONDON

From a photograph by Captain Alfred G. Buckham, F.R.P.S.

Seven Ages of Invention

BY

CYRIL HALL

Author of "Treasures of the Earth"
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SEVEN AGES OF INVENTION

CHAPTER I

Ages of Invention

From time to time, intelligent individuals—people just like you and me—blinded by disgust of the cruelty and stupidity of mankind, turn their thoughts wistfully to some land of blessedness where there are no inventions; where, in short, man can commune with Nature and search for Beauty unhindered by cupidity, superstition, smuts, or smells. Yet, because Beauty is the expression of perfect fitness, it is the very substance of invention. And, indeed, it has been man's need for Beauty that has led him to the Ages of Invention. There is no reason to suppose that he has ever been, in

the main, other than we know him to-day; there is ample evidence that just as soon as he found respite from his grim struggle with the forces that assailed him wherever he roamed upon the primeval earth, primitive man turned to invention.

Man took pains to save himself trouble. He needed leisure to nurse the spark—kindled so far down the avenues of time that we can but barely see it—that was to glow into the strange strong light supporting his sense of the things that are good to the eye and the mind's eye. So a history of invention is really a history of man's development and the slow process of civilization.

We may not be inventors, but we are undoubtedly playing a part in the unending story of invention. It is impossible to separate the story from the forces—cruel, magnificent, sublime, or grotesque—that shape all human stories. We cannot find the first vessel of baked clay, the first wheel, the first plough. We do not know where to look with certainty for the hollowed log or skin coracle in which a pioneer set forth upon the waters, nor dare we guess the forces that made such a hazard inevitable. We can take glass ornaments from the Egypt of 5000 years ago and marvel at the skill and

cunning of the hands that fashioned them, but we cannot say: "Behold this man. He first made glass!" And we can dig among the buried memories of men in Rhodesia and the caves of the Ardennes, and put a reasonable speculation on much concerning them, their periods, their habits, and their types, but all we can truly say of such memories is that they mark a stage just like any other, in the long, long journey through inventive progress.

It is only in books like this, seeking to survey in a few thousand words the accumulated science of the centuries, that inventions can be snipped like newspaper-cuttings and docketed in "Ages". The Age of Steam and Steel and Wireless and Oil, of Trouser-buttons and Fountain-pens, is very sensibly the Age of Pythagoras and Euclid. The Ages of Invention overlap just as the Iron Age and the Stone Age overlap. Necessity for the leisure that brought the finer arts and crafts to man has always been at work calling for some new thing to lighten the burdens that must be borne. It is worth observing that while in later times at all events this call has been answered almost entirely by the male of the species, it was originally the women folk of the tribe who pointed the way to leisure. Woman sewed the first fur cloak, spun the first wool,

and wove her lord's first waistcoat. She it was who grew and ground the first corn, shaped the first bowl to hold the porridge. Possibly she made the first knife for her husband's hunting, and very probably she was the founder of all the ornamental arts, not excepting that of house decorating.

No intelligent appreciation of the story of mechanical invention, which is (in the main) the field to which this book confines itself, can go forward without a survey of the contemporary facts and conditions of society. All that invention achieves or portends is summed up in that. Why, for instance, did steam and electricity wait so many centuries for their harnessing? Why were the Dark Ages so very barren of mechanical development? The answer is, of course, that society then had no need of such things. Philosophers had hinted of their possibility; but in a pastoral world, with highly organized craft guilds controlling the output of every manufactured article, what possible opening was there for a new power to move machinery that was non-existent? The Middle Ages were not unenlightened; it is a common error to confuse want of opportunity with superstition and religious bigotry.

Cruelty, cupidity, senseless persecution there

must have been in plenty, reacting against pioneers and reformers. But the harshest laws of Church or State, such as the sumptuary laws that forbade the wearing of any garment not made of wool, though cruel in their incidence, were mild and even beneficent in comparison with the hatred and self-interest set against industrial progress in the eighteenth and nineteenth centuries. The "industrial revolution" was the outcome of social developments of which anyone may read in any history book. The growth and redistribution of population that ensued, the change in one civilized country after another from an agricultural to an industrial order, the new values that suppressed and superseded old ones, the arising of new ideals and abuses—these are matters that cannot be dissociated from the story of invention. And because every one of us has a part in them still, it is a common duty to understand the causes that for ever work to shape the era that is passing.

The steam-engine came when the time was ready for it; so did the gas-engine, the railway, the motor-car. Each new thing, though its coming may bring gain in the long run, involves the passing of an older thing to which many interests — sentimental and material — have attached themselves, and so it has to fight for

existence. It does so to-day, when the patent offices of every country are nearly swamped by the conflict of new ideas and old. This fight for existence between a new idea and old rights and privileges has often been as exciting and interesting, as foolish and as futile, as the real wars between nations. Read how the textile inventions came to pass, or the era of rapid transport that George Stephenson and Edward Pease ushered in against the combined forces of prejudice and "vested interests", and you will find the pitiful, the heroic, the mean, and the magnificent blended no less than in any stirring page of history.

It is very easy to condemn the obstructionists of those times, but less easy to maintain the vision, the courage, the sense of proportion by which we are to avoid the faults they fell into. We have passed the day, perhaps, when men and women honestly saw in the progress of science forces working in opposition to the will of God. When Sir James Simpson, the Edinburgh physician who discovered that chloroform gave a merciful insensibility to the surgeon's knife, proposed to use his anæsthetic to mitigate the pains of childbirth, there was a great outcry, based not on pathological but on moral objections. At least it was better grounded

than the opposition to steamships and electric telegraphs and motor-cars. In the early days of Queen Victoria's reign, the British Colonial Office asked the Admiralty for a steamer to carry the mails between Malta and the Ionian Isles. The reply expressed " the inability of my Lords Commissioners to comply, as they feel it their bounden duty upon national and professional grounds to discourage to the utmost of their ability the employment of steam-vessels, as they consider that the introduction of steam is calculated to strike a vital blow to the naval supremacy of the Empire ". And very neatly put!

All countries can show similar examples of official denseness, but the British Admiralty was a model of this up to within comparatively recent times. When invited by Cooke and Wheatstone to consider the desirability of installing the electric telegraph for signalling between shore stations in foggy weather, My Lords replied that they were " entirely satisfied with the existing arrangements " — the " existing arrangements " being hand-worked semaphores. But bureaucratic pompousness of that kind is easier for an inventor to suffer than the State attitude that sets forth deliberately to hamper, as in the case of the notorious " Red Flag "

Act of 1865, passed to keep English roads for English horses. There are still young men who were at school when John Henry Knight defied the powers and in so doing ushered in the era of mechanical transport. In 1895, while proceeding along the high road in a home-made motor-car at six miles an hour—two miles an hour in excess of the legal maximum—he was pounced upon and prosecuted with the full rigour of the law. Although motoring was a flourishing young industry on the Continent, Mr. Knight was indicted on two counts—for not being in possession of a traction-engine licence, and for not having his vehicle preceded by a man carrying a red flag. That was the end of the Act of 1865, for ridicule and popular clamour brought about its repeal the following year.

So the Ages of Invention go forward, incapable of serious check once men's need of leisure gives them their motive force. The following chapters tell a brief tale of endeavour and fulfilment. In trying to grasp their significance, we must beware lest the dust from our own footsteps blinds us to the promise of the Age that fills the distance. At all costs let us keep our vision.

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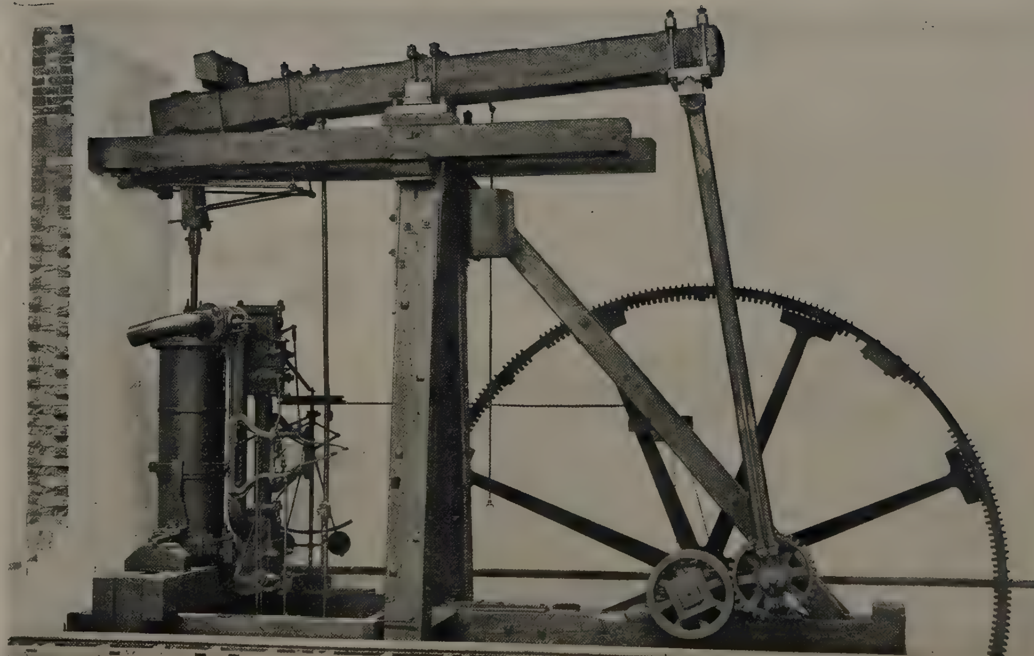

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BOULTON AND WATTS ROTATIVE ENGINE

An example of Watts' double-acting rotative beam engine, with separate condenser and air-pump, erected in 1788. It continued to work till 1858, and is now in the Science Museum, South Kensington, London

CHAPTER II

The Age of Steam

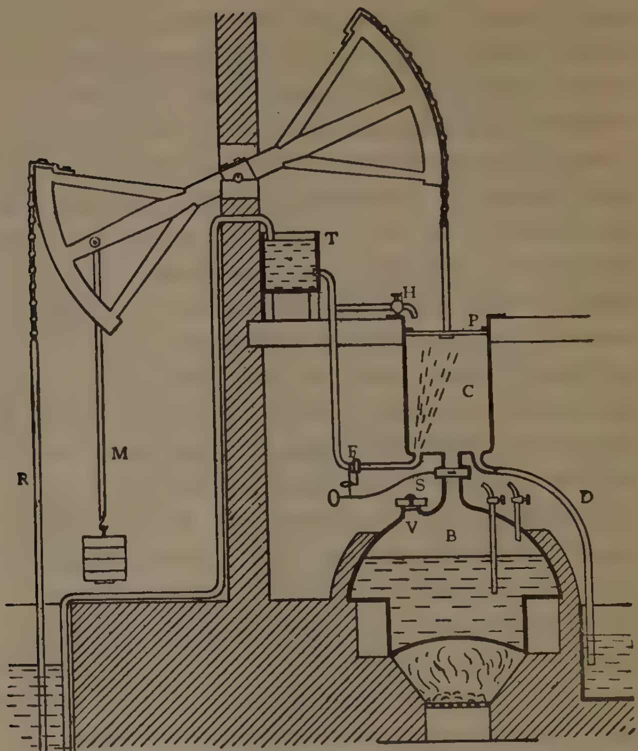
The coming of steam power was a very slow business. The sages of ancient Greece and Egypt undoubtedly experimented with it—a mysterious force that might well be a genie issuing from the kettle—but (since the time was not ready for them) their efforts led to nothing of practical importance. An Englishman, the Marquis of Worcester, born in 1601, has been called the " Inventor of the Steam Engine " Perhaps I need hardly say that he wasn't. We can't find the inventor, who must have lived long, long before the seventeenth century. But this Marquis of Worcester was a highly ingenious fellow who claimed to have produced a number of new and amazing devices. Some of them are described in his book *A Century of Inventions*, first printed in 1663. His steam-engine is referred to in his book as " an admirable and most forcible way to drive up water by means of fire ".

Delightful fellow! And his "most forcible way" was no mere figment of his imagination, but an accomplished and tangible engine which all men might see who chose to walk down Vauxhall in London between the years 1663 and 1670. It really did useful work in pumping water. Now, it must be understood that this invention of the Marquis of Worcester's was not a steam-engine in the modern sense of the word. It made no use of the expansive force of steam as in the piston or "reciprocating" engine, or as in the steam-turbine; it did its work by making use of the weight of the atmosphere. A boiler supplied steam to two vessels, in which, as the steam rapidly condensed, a vacuum was formed. The result was that the weight of the air acting on the surface of the water to be raised forced it into the vessels; the valve of the suction-pipe was then closed, and when steam was again admitted to the vessels, then full of water, its pressure ejected the water past the delivery-valve. And, with variations, that was the principle of the steam-engines that followed for a hundred years or more, until James Watt took the matter in hand.

Pumping was the sole purpose and endeavour of the early steam-engine inventors, and they

were alike in seeking to make the air do their work, rather than the tremendous power of steam. They did not know that when water is changed into steam its volume increases 1600 times. But they knew that without pumps far more powerful than any worked by hand, all the mines in England were in danger of falling into disuse. At that time, the known seams of minerals had been worked on the surface for so long that the miners had reached the levels at which water gathered and were unable to go deeper into the earth. It was therefore a very real need that the successors of the Marquis of Worcester set themselves to meet.

The next to turn his hand to the steam-engine—or "fire-engine" as it was then called—was a Captain Savery, who took out a patent in 1698 for the application of steam power to various kinds of machinery. Savery's engine was merely a modification of the Marquis of Worcester's, but such engines were used to some extent for draining mines in Devonshire and Cornwall. A very great step forward was made when Henry Newcomen applied himself to the improvement of Savery's engine. After 1705 Newcomen's engines became extensively employed in water-logged mines, and although they were clumsy and extraordinarily wasteful



Section of Newcomen's Atmospheric Engine, 1705 (*after Stuart*)

B, Boiler. S, Steam-cock admitting steam to cylinder C. P, Piston attached to wooden beam pivoted on its centre. V, Safety valve. F, Cold-water inlet to cylinder, from tank T. H, Water supply to top of piston to keep it airtight. D, Injected water escape pipe. M, Counterweight. R, Pump-rod.

they held their own as mechanical prime-movers for nearly seventy years.

Newcomen's engines did not depart from the

atmospheric principle of the earlier inventors; but the introduction of a beam for the transmission of the power gave them a much wider application. Imagine a massive wooden beam pivoted on its centre. One end of the beam was linked to a pump-rod, the other end was linked to a rod attached to a piston moving in a cylinder connected by a steam-cock with the boiler, to admit or cut off the steam. Now, it followed that when the steam raised the piston to the top of the cylinder, the pump-rod end of the beam was depressed. The steam was then cut-off, and another tap was opened to allow a dash of cold water to flow on to the upper side of the piston. This caused the steam quickly to condense, forming a vacuum below the piston, which was thus forced down by the weight of the air. As the piston fell, it brought down its end of the beam, and so raised the other end carrying the pump-rod. The water from the condensed steam was then drained from the cylinder, steam was readmitted to force the piston up again, and so the cycle was repeated.

There is an interesting story concerning the control of the various taps and steam-cocks necessary to the working of Newcomen's early engines which shows how improvement comes sometimes in an unexpected way. Newcomen

was a practical engineer whose name has justly been honoured for more than 200 years. But very few people have ever heard of Humphrey Potter, a boy who liked to save himself trouble. It was Humphrey's task to turn the several cocks by which the cycle of operations was maintained —the admission of steam, the jet of cold water for condensing, the draining of the cylinder, and the rest—but he seems to have found engine-minding irksome, and that he might leave himself more free to play, he rigged up a system of cords and levers by which the engine was made to work its own valves; and so there came into being the first *self-acting* steam-engine.

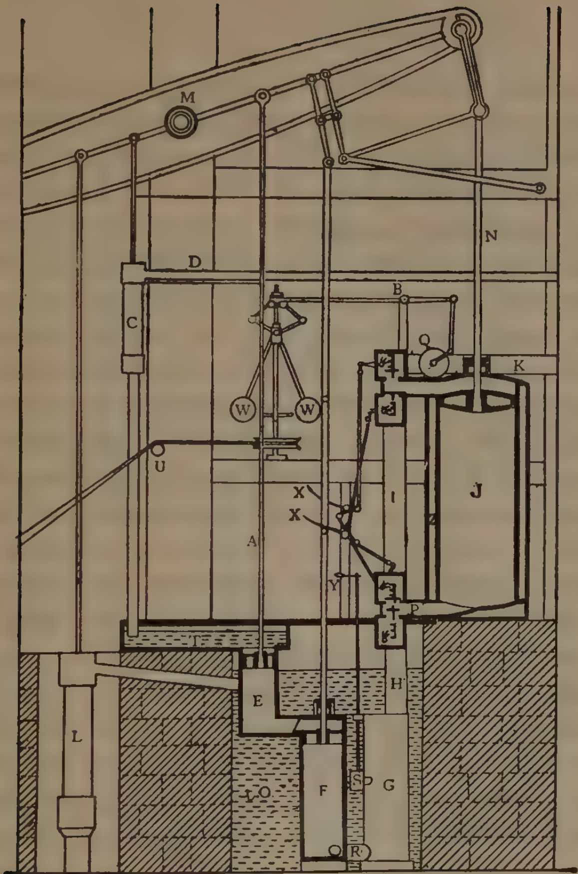
Newcomen's engine was improved from time to time by other inventors, but it was left to the genius of a Scottish mathematical instrument maker to give birth to the engine that really ushered in the Age of Steam. James Watt was the son of a merchant of Greenock. He was too delicate a child to go to school, but he was ably taught at home and started life as a maker of mathematical instruments, and used his time and talents to such good purpose that he was appointed mathematical instrument maker to the University of Glasgow and was given a workshop within the university. The

curriculum, of course, included a class in natural philosophy, and a model of Newcomen's steam-engine used by that class having gone wrong, it was sent to Watt's workshop for repair. Although not exactly in his own line of work, Watt soon mended it and had it going as well as ever, but the task called his attention to the faults of the engine and fired him with the idea of improving upon it.

By his invention of the separate condenser, Watt, at one step almost, had at his service an engine at least ten times more powerful than Newcomen's, for a given consumption of fuel. He saw at once that the injection of the cold water into the open cylinder of Newcomen's engine, in order to condense the steam under the piston, was terribly wasteful of heat. Of the steam admitted to force the piston up again, not more than a quarter was actually lifting the piston, three-quarters of the total amount entering the cylinder being needed to reheat it above condensation point. So Watt closed in the open cylinder and led the spent steam to a separate condenser. And he further conserved heat by putting an outer jacket about the cylinder and keeping a space between the two filled with steam. That was in 1769. It was the first time the principle of steam *pressure* was applied as

a sole motive power, and from the changes it was to bring about in the wealth and productivity of civilized peoples it marked the beginning of a new era in history.

Watt is an example—very rare amongst the pioneers—of a truly scientific and philosophical inventor. The skill of his hands is revealed in his calling; and the story of his life-work shows that his inventions were the outcome of patient experiment and research. It was by experiment that he was able to make the first engine in which use was made of the *expansive* power of steam, and thus to lead the way to the steam-engine in its modern form. His first engine, having a closed cylinder and a separate condenser (that was such a vast improvement on Newcomen's), worked, as has been said, by the *pressure* of steam. That is to say, the velocity of the jet of steam impinging on the piston actually pushed it upwards and downwards. It was Watt's appreciation of the fact that steam is a gas capable of enormous expansion that led him to construct an engine in which this power of expansion was utilized. He arranged to cut off the steam when only a portion of the piston's stroke had been effected and to make the expansion of the steam complete the stroke. Though this resulted in some loss



Section of Watt's Double-acting Engine, 1782 (*after Stuart*)

J, Cylinder enclosed in jacket of steam or air. N, Rod attaching piston to lever-beam M. XX, Levers operating valves. I and K, Steam inlet pipes from boiler. G, Condenser connected to cylinder by pipes H and P. W, Governor, connected by endless chain running over pulley U to flywheel. It controls steam-valve Q. F and E, Air-pumps raising water from condenser to trough T and thence by pump C and pipe D back to boiler. L, Cold-water pump supplying reservoir in which the condenser and its pumps are placed.

of power in an engine of any given capacity, there was a great saving of steam and consequently of fuel.

In many other ways did James Watt improve the steam-engine, until by 1784 it had attained the form in which, with modifications, it still survives. By an arrangement of valves to admit the steam first to one side of the piston and then to the other, so that each stroke was a power stroke, he produced the "double-acting" engine. He invented the governor to control the speed of the engine, the throttle-valve to feed it with steam; and more important still, the form of connecting-rod, crank-shaft, and fly-wheel by which means the up-and-down motion of a clumsy beam was dispensed with and a true rotary motion attained that could be more easily applied to all kinds of work.

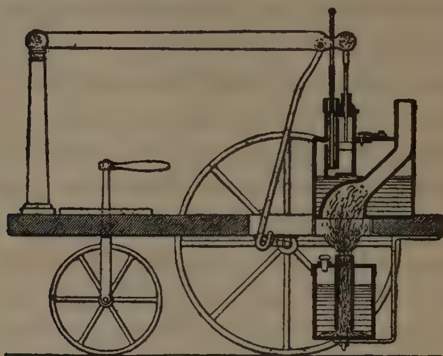
In 1774 Watt entered upon his famous partnership with Matthew Boulton, a step of the greatest importance, for if it had not been for Boulton's enterprise and large imagination, it is doubtful if Watt would have had the courage to push his inventions into notice. And this brings us to another very famous inventor, Boulton and Watt's assistant, Murdoch.

This William Murdoch was the inventor of

the system of lighting by means of coal-gas, and Boulton and Watt's workshop at Soho, near Birmingham, was one of the first buildings illuminated by this method. Murdoch did not gain either much profit or renown from this very useful invention, and, indeed, many of his lesser inventions are obscured by the much greater credit due to him for his work on the steam-locomotive. Murdoch, after some years spent with Boulton and Watt at Soho, was sent to Cornwall to take charge of the erection of mining engines, and while there he turned his attention very earnestly to the design of the steam-locomotive. It was known that such a machine was feasible, but all existing ideas embodied very serious defects. But Murdoch had every intention of overcoming the difficulties. He would spend his spare time, in the evenings when his laborious day's work was over, in building a model of his steam-carriage—which may be seen to-day in the Birmingham Art Gallery. To our eyes it is an inconceivably clumsy and unwieldy contrivance, but no doubt to Murdoch it was the beautiful child of his imagination and therefore immensely precious and wonderful.

The carriage was mounted on three wheels, of which one small one in front was used for steer-

ing only. Spirit burnt in an open vessel heated the water in the boiler. Murdoch worked in secret, and on that account did not venture far with his carriage; but on one occasion, on a very dusky evening, he drove it out of the lane in which his cottage was situated on to the



Section through model of Murdoch's Steam-carriage

main road, hoping that it would be as deserted as usual. There was, however, one wayfarer—the vicar of the parish. The worthy man was returning home after an unusually long round of visits when a strange and horrible noise fell upon his ears, accompanied by a strange smell. Next he was appalled to see a hideous object approaching him, lighted by fitful flames. When he perceived something resembling a human form riding in the midst of the flames, he waited

no longer but fled precipitately, and seasoned his discourses ever after with solemn declarations of his vision of the Evil One. The incident put a stop to Murdoch's trips abroad, and he thereafter confined his engine to the shed in which it was built, but the fame of it gradually spread until in due time it was reported to Boulton and Watt. They, not wishing to lose so fine a workman, offered Murdoch a large salary to return to Soho as general manager, a position which he amply justified. His was the real inventive genius, and he was continually trying new methods and introducing new mechanical devices for the saving of labour and improvement of output.

Though Murdoch himself went no further with the steam-carriage, his Cornish pupil and assistant, Richard Trevithick, carried the matter many steps nearer success. The use of rails to facilitate wheeled traffic is very ancient. The Romans used them, and all heavy transport in mines, quarries, and the like was effected by horse-drawn wagons running on rails. But these early steam-carriages were made to travel on the ordinary road surface—generally a very bad one. Trevithick it was who first tried the experiment of running a steam-carriage on rails and actually the first steam-train to run on a

railway operated at Pen-y-darran Ironworks, in South Wales, in 1803. Trevithick built the engine and constructed the track on which engine and trucks were to run.

After Trevithick's time various experimenters took their turns at trying to perfect the steam-locomotive, always in the face of opposition and ridicule. News travelled slowly in those days, but the tale of the steam-carriage was slowly permeating the country. Most men scoffed, parsons denounced it as impious, only a few were far-sighted enough to see in it the motive power of the future. But there were external conditions which had a great influence on the growth and development of the locomotive. The Napoleonic Wars were at their height, with the inevitable result that horses and the fodder for horses were prohibitively dear. The problem of haulage was becoming more and more difficult. Only the poorest of horses were available for such work, the better ones having been commandeered by the military—mules were found to be refractory and bullocks too slow—and all wanted feeding.

A few of the more progressive mine-owners saw in these circumstances the great possibilities of an inanimate motive power which would consume fire and water instead of

hay. Such a one was Christopher Blackett. Having heard of Trevithick's engine at Pen-y-darran, he determined to experiment with steam-locomotives at his colliery at Wylam, near Newcastle-on-Tyne. The next ten years were occupied with Blackett's trials and troubles with several fiery monsters on the six-mile tramway from his pits to the loading staiths on the Tyne. They are rightly entertaining monsters too, including "Puffing Billy" of 1813, now in South Kensington Museum, and his dainty sister "Wylam Dilly", still preserved at Edinburgh; but we cannot stop to speak of them, except to say that their inventors pointed the way to success to George Stephenson.

Stephenson was born in a cottage fronting Blackett's railway, and so he grew up with the rattle of the locomotive in his ears, and as soon as he was old enough he found employment at the colliery where his father worked. He had no education until he reached the age of seventeen, when, finding he could get no further in his trade without a knowledge of reading and writing, he applied himself to learn. His observation and memory were always occupied in storing up the knowledge he derived from his daily association with engines, his acute mind noting their weak points and ever pondering on

methods of improvement. It was not until 1814 that he had an opportunity of putting his theories to the test. By that time he had a good position as enginewright at Killingworth Colliery, of which the owner was Lord Ravensworth, an enterprising and progressive man. He it was who provided Stephenson with the money to build his first locomotive—appropriately named "My Lord"—to haul trucks on the colliery.

So far steam locomotion had been confined exclusively to mine workings. The jolting was excessive, and only materials of an indestructible type could be carried with any degree of safety. But, in a few years, Stephenson's colliery locomotive revealed to the harassed mine-owners a way of escape from their transport difficulties. The social conditions of the time were ready for the coming of the railway, and there were economic peculiarities that pointed to the north-east corner of England as its appropriate birthplace. By 1818 Stephenson's locomotives could haul a load of sixty tons at a speed of four or five miles an hour, and a year later a scheme was projected for a railway between the two busy manufacturing towns of Stockton and Darlington. This was to be a public railway, but it must be understood that at that time a railway

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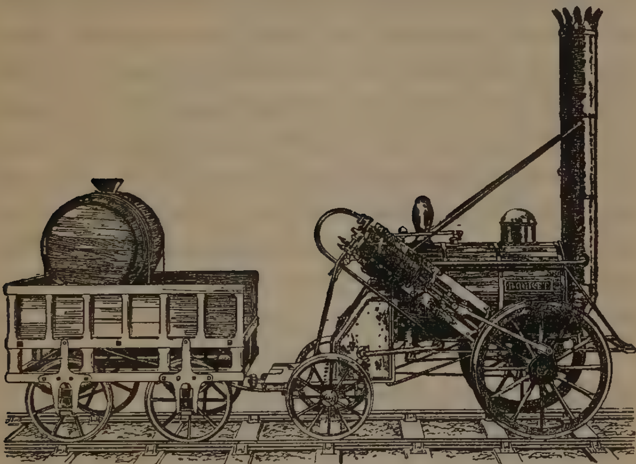
THE "FLYING SCOTSMAN"

Beginning its non-stop run of 392 miles from London (King's Cross) to Edinburgh

simply meant a track with rails, on which the public could travel in their own carriages drawn by their own horses, or send goods in horse-drawn wagons, on payment of tolls. It was simply applying to public traffic the principle



The "Rocket" Locomotive built by Messrs. R. Stephenson & Co. in 1829. Now in the Science Museum, South Kensington, London

of rails which had been found to facilitate the haulage of minerals.

The promoter of the scheme was Edward Pease, a financier of Darlington, but he found himself faced with very great opposition. It was not until 1821 that the necessary Acts of Parliament were finally passed. Hearing that the project

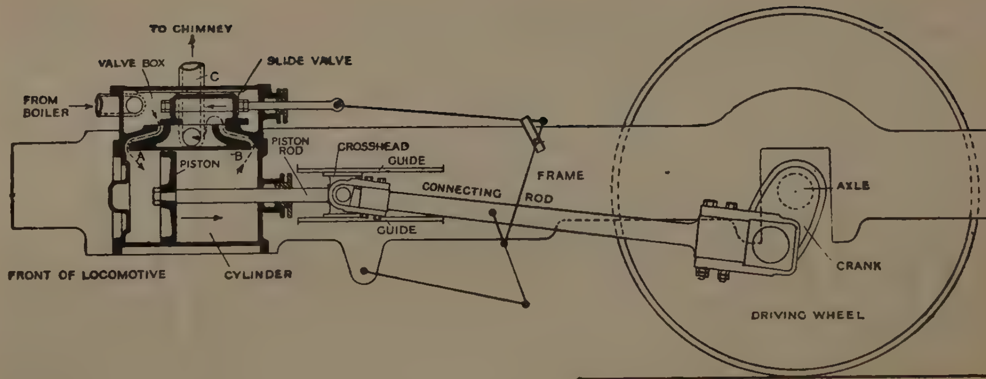
was really to go forward, Stephenson called on Pease to offer his services in the construction of the line, which were accepted. The visit had another result of far greater importance: Pease became interested in the development of steam locomotion, and by his efforts the Act of Parliament was amended to allow the use of locomotives on the line. Although most of the directors of the railway were completely sceptical of the possibilities of the travelling engines, Stephenson was instructed to build three at his new works at Newcastle, and the railway was formally opened on 27th September, 1825. The first train was drawn by "Locomotion Number 1" and was made up of six wagons carrying flour and coal, the two staple commodities of the district, a coach for the directors of the railway and their friends, twenty-one wagons for passengers, and six more trucks of coal—a total of thirty-eight vehicles. An eye-witness thus described the event:

"The signal being given, the engine started off with this immense train of carriages, and such was its velocity, that in some parts the speed was frequently twelve miles an hour!"

It is a far cry from the uncouth and unreliable railway engines of a hundred years ago to the powerful giants that speed along the world's rail-

ways to-day. But there has been remarkably little change in the essentials of design, such change being mostly in the rearrangement of the component parts and in the continual need for increased efficiency. All travelling engines have a common peculiarity that is also a disability: they must carry with them their own supplies of fuel as well as the means of converting it into heat. In other words, engine and boiler are parts of a single unit, and the locomotive engineer's problem lies in how best to combine them in a space that is governed by such unyielding conditions as the width of the track and the height of bridges and tunnels. And while with every new demand for increased tractive effort he needs more and more weight to give adhesion to the rails, it may be the case that the track itself is not strong enough to bear the strain. So that each development in the weight and power of locomotives has involved a corresponding improvement in the rails and the road-bed carrying them. Indeed, there are many railways on which the locomotives now weigh as much as did the express trains of thirty or forty years ago.

It is because of its strict limitations of weight and size, and because the steam-raising plant is an essential part of it, that the locomotive engine



Engine of Locomotive

Steam from the boiler enters the valve chest or box. It then passes down the passage A into the cylinder. Its pressure drives the piston forward, and the spent steam upon the other side of the piston is forced up the passage B, under the slide valve, and away up the chimney. When the piston reaches the end of the cylinder, the valve has moved over so that fresh steam from the valve box now enters from the passage B, driving the piston back again. The steam on the left side now escapes under the valve and away to the chimney. In this way the piston is driven backwards and forwards continuously.

The piston-rod connects the piston to the cross-head, which slides between the guides. The motion of the cross-head is transmitted to the crank on the axle of the driving-wheels by the connecting-rod. The other wheels of the engine are left out, as they would confuse the diagram.

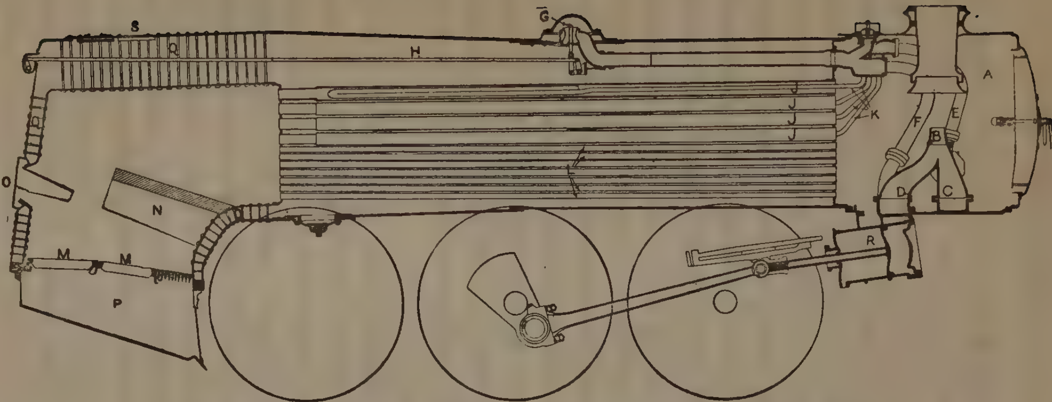
is one of the most beautifully perfect machines man has evolved. Neither in speed nor in economy of working certain conditions of traffic can it compete with its new rival electricity, because electricity can be made in enormous quantities in a central station and conveyed quickly and cheaply to any number of power-units. To operate a given volume of traffic, electric power can be increased at will or diminished at will in a way not possible with steam-locomotives. But, in spite of that, the steam-locomotive has still an undisturbed sphere of usefulness and will remain a constant and familiar feature of railway working for a long time to come.

There are very few people who are able to resist the spectacular appeal of a giant locomotive. Great romance is indeed hidden in the bulky mass weighing a hundred and fifty tons or more thrashing onwards over the land with its multitude of passengers, a miracle of unerring precision. Consider the mechanical perfection revealed in the performance day after day, week after week, of the non-stop runs of 400 miles accomplished by the Scotch expresses. Engines that as their regular duty can make non-stop runs with heavy loads for such distances embody a hundred years of pro-

gress in a way that touches the imagination very forcibly.

An interesting point about the history of the steam-engine is that while the present-day steam-raising plant has passed out of all recognition from the boiler of James Watt, the locomotive boiler remains much in the form given to it by the hands of George Stephenson. The high-capacity stationary boiler consists of batteries of cylindrical vessels connected by tubes, the whole being set in brickwork. They are fed with coal by a mechanical apparatus, and the hot gases are made to traverse complicated flues and passages in order to make them give off as much heat as possible before they are finally discharged into the air. The same principle, of course, applies to the locomotive boiler, the object being to convert into power as many as possible of the heat units contained in the fuel. But whereas in stationary boilers the almost universal practice is to pass the water through a great number of tubes surrounded by burning gas, in the locomotive boiler this arrangement is reversed, and the burning gas is made to traverse tubes which are surrounded by water.

In a locomotive the boiler has three main divisions. The fire-box extends from the foot-



Section of the Fire-box and Boiler of a modern London and North-Eastern Locomotive

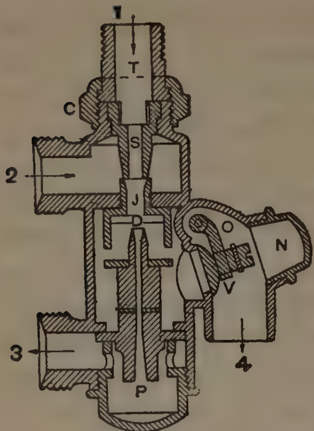
A, Smoke-box. B, Blast-nozzle. C, Exhaust from outside cylinder. D, Exhaust from inside cylinder. E, Superheated steam-pipe to outside cylinder. F, Superheated steam-pipe to inside cylinder. G, Steam-pipe head. H, Regulator rod. I, Main steam-pipe to header. J, Superheated fire-tubes. K, Superheated elements. L, Fire-tubes. M, Fire-bars. N, Fire-brick arch. O. Fire-hole door. P, Ashpan. Q, Fire-box stays. R, A cylinder.

plate to immediately behind the last pair of driving-wheels, a depth of from 8 to 10 feet. It is made with an outer and an inner shell, the space between being filled with water. The two shells are immensely strong and are rigidly held by stays. A long barrel fixed to a ring in the outer shell of the fire-box forms the obvious part of the boiler and communicates with a smoke-box in the front of the engine. From the back of the fire-box a great number of small tubes—there are generally 1500, sometimes 2000, of them—pass lengthways through the barrel of the boiler to the smoke-box. They convey the burning gases from the fire-box to the funnel, and in doing so they expose an enormous heating surface to the water surrounding them.

In some locomotives there are water-tubes as well as these invariable fire-tubes; and in order to make use of all the heat that can be used, most modern locomotives are fitted with superheater devices in which the steam is passed through pipes in direct contact with the burning gases and so heated to a very high temperature before admission to the engine cylinders; and with the same object, the water supplied to the boiler is also heated by the waste gases. But, in spite of every anti-waste

device, both in the boiler itself and in the beautifully-designed engine in which every ounce of steam generated is made to do its full share of work before it is forced, quite spent, out of the cylinders and through the blast-pipe that maintains the draught for the fire, not more than a quarter of the heat units in the fuel are converted into power. And that is a very lamentable state of affairs, because the world's supplies of carboniferous fuels in the two forms —coal and oil—in which they are now chiefly used are available only in strictly limited and ever-lessening quantities.

Mention was made just now of the heating of the feed water. The method by which this is forced into the boiler is exceedingly interesting, the apparatus by which it is accomplished being one of the most ingenious ever invented. For a long time engineers relied upon force-pumps for feeding their boilers, the pumps being worked from some part of the engine motion. But as engine speed and boiler pressure alike grew higher and higher, the need grew for a more satisfactory device. It was Henri Giffard, a Frenchman, who met the need with the steam injector, a contrivance in which a jet of steam is made to force water past a valve into the boiler.



Penberthy Injector

S, Steam jet. P, Plug. O, Overflow hinge. J, Suction jet. T, Tail pipe. V, Overflow valve. D, Delivery jet. C, Coupling nut. N, Overflow cap.
1, Steam inlet. 2, Water inlet. 3, To boiler. 4, Overflow.

Now, the injector implies a paradox; for how can steam taken from a boiler working at a pressure of, say, 300 lb. to the square inch force into the same boiler many times its own weight of feed water? More amazing still, how can the *spent* steam from the engine - exhaust force water into the boiler against ten times its own pressure or more? This, nevertheless, is what the injector actually does, without any moving parts other than the valves for regulating the supply of steam and water. What really happens is that the *velocity* of the steam is increased until it is more than sufficient, when imparted to a stream of water, to force the latter against the pressure in the boiler. Reduced to its very simplest form, the injector consists of two hollow cones, one within the other. The outer cone communicates with the feed-water supply, and the inner with the steam from the

boiler. Now, by being made to pass through the nozzle of the cone the steam is given a very high velocity. And as soon as it comes in contact with the water in the outer cone, some of it condenses, thus creating a partial vacuum, into which, of course, the water rushes. The impact of the jet of steam gives a terrific velocity to the water in the injector—a velocity as high in some cases as 1000 miles an hour. The great momentum of this column of steam and water acts like a battering-ram on the boiler valve, forces it open, and literally squirts the water into the boiler.

The tremendous power in the velocity of steam led to an invention far more important than the injector. It was Sir Charles Parsons' investigation of the subject that gave the world a form of prime mover that revolutionized the existing theory of the steam-engine. It is not, of course, to be supposed that all the steam-engine designers since the days of Watt had been content to accept without a struggle the many defects and deficiencies of the reciprocating engine. Device after device was tried to make it more efficient and economical. Every advantage was taken of the expansive power of steam by making it do work in cylinder after cylinder, until triple- and quadruple- and

even quintuple-expansion engines were in use, until at last it appeared that further economy could only come from improvement in the methods and contrivances for raising steam.

The question that Sir Charles Parsons set himself to answer was whether it was not possible to employ the velocity of steam to rotate a shaft in much the same manner as the velocity of water is used in the water-wheel. If that could be done, the mechanism necessary for the conversion of the to-and-fro motion of the reciprocating engine to the rotary motion of the shaft—pistons, piston-rods, connecting-rods, cross-heads, cranks, eccentrics, and the like—could be entirely done away with. All such intermediate machinery naturally involves a great waste of energy in the friction set up by its movement. This loss could be saved if the steam were made to turn a shaft by impinging directly on blades of a wheel attached to it.

Sir Charles Parsons was not only a practical engineer, he was an inventor by birth and inclination; and more, he had a mind accurately trained in scientific investigation. He was a son of a distinguished father, the Earl of Ross, who had built what was then the largest telescope in the world; and he was brought up in

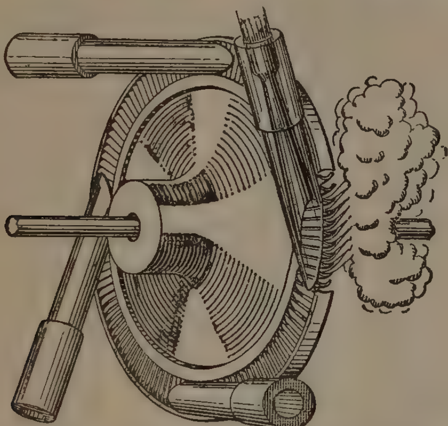
a circle in which the study and scientific application of mechanics were daily meat and drink to him. He was a young man of thirty when he built the first engine on his new rotary principle. That was in 1884; and that engine—the first steam-turbine—was as revolutionary in the change it wrought in the application of steam power as James Watt's condensing engine nad been 115 years earlier. It was destined to provide a form of steam prime mover admirably adapted for the growing demand for electrical generators and to meet the need for the cheaper and quicker propulsion of ships—an engine at once economical, noiseless, and vibrationless.

It is not to be supposed that the inventor had things all his own way. Such a happy state of affairs does not happen to inventors any more than to the rest of us. And, as a matter of fact, the Parsons turbine of 1884 was of no practical use other than the purpose it served in demonstrating the feasibility of its inventor's theory. It was terribly wasteful, and it ran at such an alarming speed—nearly 18,000 revolutions a minute—that no dynamo could withstand the strain. Subsequent efforts failed generally to impress or convince engineering experts; while at the very moment when success

seemed assured, the inventor broke with the engineering firm with which he was working and was forced to leave in their hands the—to him—immensely valuable patent rights he had acquired. He had additional cause for anxiety in the almost simultaneous invention by a Swedish engineer of a steam-turbine that quickly gained favour on the Continent. This was the De Laval impulse turbine, in which little jets of steam were made to turn a wheel revolving in a cylinder.

By 1891 Sir Charles Parsons had so improved his turbine that one installed at the Cambridge electricity works proved as economical as the best form of reciprocating engine. Three years later, the new power was applied for the first time in a ship, but the *Turbinia*, as this very famous little boat was called, was at first a failure. Although the propeller spun round 1500 times a minute, the speed of the little vessel was disappointingly slow. Her trials raised a new problem—now known as cavitation—which took some time to solve. Experiments were made with the propeller running in a glass-sided tank, through which photographs could be taken; and it was found that the propeller, instead of spinning round in the water, was spinning round in a little air-space or cavity

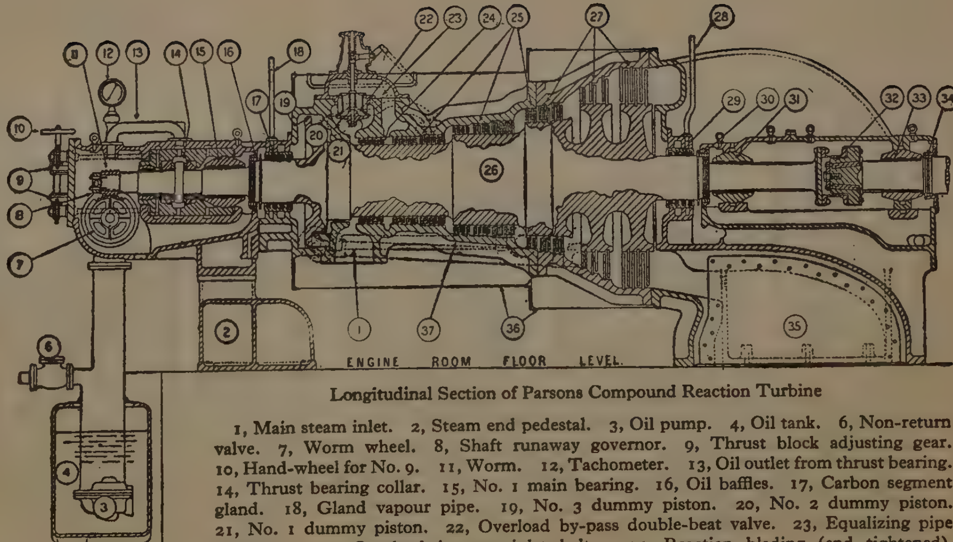
which it made for itself. The experiment led to alterations in the *Turbinia's* screws, and her day of glory came in 1897, when, at a great naval review, she astonished seamen by darting hither and thither at a speed of 34 knots. It was not many years before the turbine came to



View of Wheel of De Laval Steam-turbine, showing Action of Steam

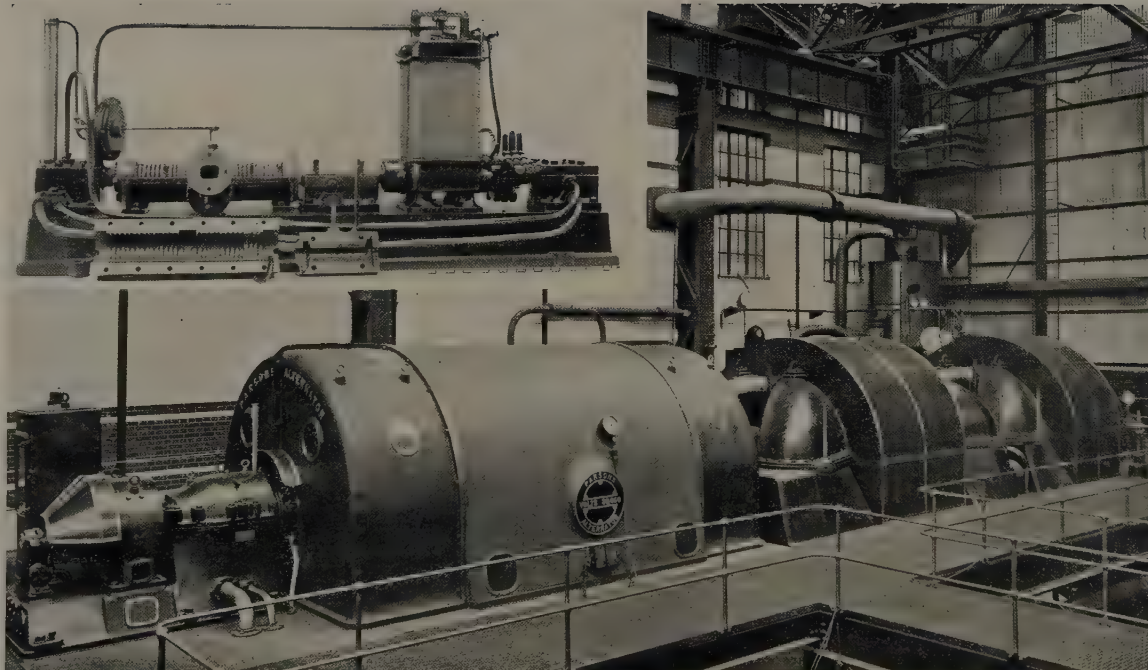
be recognized as the supreme method of propulsion for high-speed ships.

A Parsons turbine consists of a drum mounted on a central shaft and turning in a steam-tight case. The drum carries a great number of rings to which are fastened tens of thousands of small vanes, called blades. Now, in the De Laval turbine the steam impinges directly on the



Longitudinal Section of Parsons Compound Reaction Turbine

1, Main steam inlet. 2, Steam end pedestal. 3, Oil pump. 4, Oil tank. 6, Non-return valve. 7, Worm wheel. 8, Shaft runaway governor. 9, Thrust block adjusting gear. 10, Hand-wheel for No. 9. 11, Worm. 12, Tachometer. 13, Oil outlet from thrust bearing. 14, Thrust bearing collar. 15, No. 1 main bearing. 16, Oil baffles. 17, Carbon segment gland. 18, Gland vapour pipe. 19, No. 3 dummy piston. 20, No. 2 dummy piston. 21, No. 1 dummy piston. 22, Overload by-pass double-beat valve. 23, Equalizing pipe (dotted). 24, Overload by-pass inlet belt. 25, Reaction blading (end tightened). 26, Turbine shaft. 27, Reaction blading (ordinary radial clearance). 28, Gland vapour pipe. 29, Carbon segment gland. 30, Oil baffles. 31, No. 2 main bearing. 32, Flexible coupling. 33, No. 3 main bearing. 34, Oil baffles. 35, Turbine exhaust. 36, Cylinder lagging. 37, Equalizing pipe (dotted)



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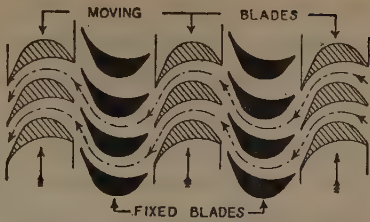
By courtesy of Messrs. C. A. Parsons & Co., Ltd.

TURBINE-DRIVEN GENERATORS OF ELECTRICITY

The upper picture shows the original Parsons steam turbine driving a dynamo. It is now in the Science Museum, South Kensington, London. The other picture shows one of two 25,000 kw. 3000 r.p.m. tandem turbo-alternators. This alternator generates current at a pressure of 33,000 volts



The Arrangement of the Blades in Parsons' Steam-turbine

The moving blades are attached to the drum of the turbine. The fixed blades are attached to the inside of the casing in which the drum revolves. Steam enters on the right, striking the first row of moving blades. It is then guided by the first row of fixed blades on to the second row of moving blades, and so on until it escapes at the end of the turbine. The force of the steam upon the moving blades drives them, and the drum to which they are attached, round. The blades will be seen in the picture opposite

blades on the rotating drum. The Parsons turbine, however, belongs to what is known as the reaction type, in which the steam first of all strikes against fixed guides forming part of the casing. Between each of the many moving rings of blades there is a stationary ring of fixed guides through which the steam must pass before it can reach the moving blades. As the steam enters the turbine it is broken into a great number of jets by the first ring of guides, each jet striking a corresponding blade on the drum. And as the drum begins to turn, the steam passes between the second ring of guides and blades, and then the third, and so on until it finally emerges from the turbine into the condenser. In order to make use of the expansive power of the steam, the rings of fixed guides and moving blades are made in series that

increase in size. In marine turbines, simple gearing is interposed between the turbine-shafts and the propeller-shafts, and separate turbines are necessary for reversing.

Modern turbines work with steam at a very high pressure—well over 500 lb. to the square inch, or more than thirty times that used in the boilers of James Watt.[1] But it is none the less a fact that the turbine is so economical that it is able to make good use of the expansion of low-pressure steam. Indeed, turbines are sometimes put down to run on the waste steam exhausted by reciprocating engines; and it is common practice in works to employ two separate turbines, a high- and a low-pressure. The exhaust steam from the high-pressure turbine is sent round the works in pipes, heating vats and appliances for various processes, and keeping the workpeople warm. And having performed that service it enters a low-pressure turbine coupled to a dynamo, where the last pound of its expansive force is converted into electrical force.

It is, indeed, as an electric generator that the turbine excels. It is but a quarter of a century since the first turbine-driven liner—the Allan

[1] Water-tube boilers are in operation at pressures exceeding 1250 lbs. per square inch.

Liner *Victorian*—crossed the Atlantic. That marvellous turbine ship the Cunarder *Mauretania* has gone on breaking records and piling thrill on thrill ever since she was put in commission in 1907. In 1928 she made the fastest voyage from New York to Plymouth—five days six minutes—and in the same month created two other new records. But the electrically propelled ship is rapidly gaining favour. The new P. & O. mail steamer *Viceroy of India* will have propellers turned by electric motors of 18,000 h.p., for which high-pressure turbines will generate the power. And it is not unlikely that the 60,000-ton leviathan which was laid down for the White Star Line in the summer of 1928 will not be directly propelled by turbines, but by turbo-generators supplying current to electric motors.

CHAPTER III

The Age of Steel

A century of progress has brought so vast a stream of scientific application and research that it is not easy to form a picture of the inventor's workshop as it was when Boulton and Watt started the first steam-engine factory in 1774. In the light of our superior knowledge we smile, possibly, at the clumsiness or crudity of some fundamentally significant piece of machinery, forgetting that it could not be otherwise than crude—"rude" is perhaps a better word—when the tools and materials to fashion it were incapable of higher attainment. The early engineers and inventors were obliged to work with the rough appliances of the village blacksmith—an open-hearth furnace and bellows, anvil, and hammers—and to employ wrought iron of very unreliable quality. There were rough and very inaccurate machines for drilling and turning; but the larger and heavier parts of machinery had to be cast in iron and labori-

ously finished by hand. There were no accurate gauges or measuring instruments until 1820 or thereabouts, when the inventive genius of Henry Maudsley provided engineers with a standard of accuracy hitherto unknown. Until Maudsley made a screw-cutting machine no two nuts and bolts, though nominally of the same size, were quite the same as any other two; and it was the practice in those early days, as we are told by James Nasmyth, the inventor of the steam-hammer, to give to every bolt and nut a distinctive mark to avoid the mischance of getting them mixed with others. If the nut belonging to a given bolt was lost or mislaid, there was a very poor chance of finding another to fit. Compare this with the present standard of precision, which requires that the rollers for roller-bearings of the crank-shafts of motor-car engines must not vary from the prescribed diameter by more than three ten-thousandths of an inch.

Accuracy of such a standard is a truly wonderful accomplishment, but it is surpassed, I think, by the precision attained in the building of the great British airship R101. The framework of this vessel, which has a length of 700 feet, is made of girders composed of many miles of steel tubing. This tubing itself is a masterpiece

of metal-working. Long strips of very thin, springy steel enter a machine and emerge therefrom as very strong, rigid, circular tubes, with interlocked flanges, from which the curved triangular girders, 45 feet long, are built up. The girders were made in a factory miles from the place where they were eventually to form the framework of R101, and the truly marvellous thing is that it is possible to make them with a fractional error in dimension not exceeding thirty one-thousandths of an inch. That means a maximum variation, between similar parts 45 feet long, of about the thickness of a visiting-card.

For the creation of his inventions, the mechanic of the early nineteenth century had at his disposal wrought and cast iron, the costly hand-made steel from which tools and weapons were forged, and copper and its alloys. Now, of these metals, iron and steel alone are capable of withstanding the strains and stresses set up in moving masses of machinery. How great these strains may be in so small and simple a contrivance as, let us say, a bicycle, is astonishing even to the engineer. The hammering effect of smooth wheels running on a smooth railway is such that wheels and rails constantly broke when the first railways were built. The centri-

fugal force acting on the periphery of a fly-wheel turning at high speed is enormous, and burst fly-wheels scattered death and destruction through many factories when the application of steam began to be general.

The grandest machine is but an idle dream until there exist the means to fashion it, and in order that inventors' dreams may take shape quickly, there has moved hand in hand with them, as it were, a secondary group of discoverers whose efforts have been directed to provide the most suitable and reliable materials for their use. Without these discoverers—the metallurgists and research-workers—machinery of all kinds would still be primitive and clumsy, and the thousands of beautiful appliances that are commonplaces of factory production would be still practical impossibilities. Imagine what your bicycle would be like if, instead of knowing exactly what strains every separate part of it had to bear, and what strains every part of it *can* bear with absolute certainty, the maker had trusted to chance, allowing a fair bit of extra material as a safety margin. Of all that he uses the inventor nowadays knows the exact qualities and capabilities, and in that knowledge he possesses an incalculable advantage his predecessors lacked. And he has a vastly wider range from

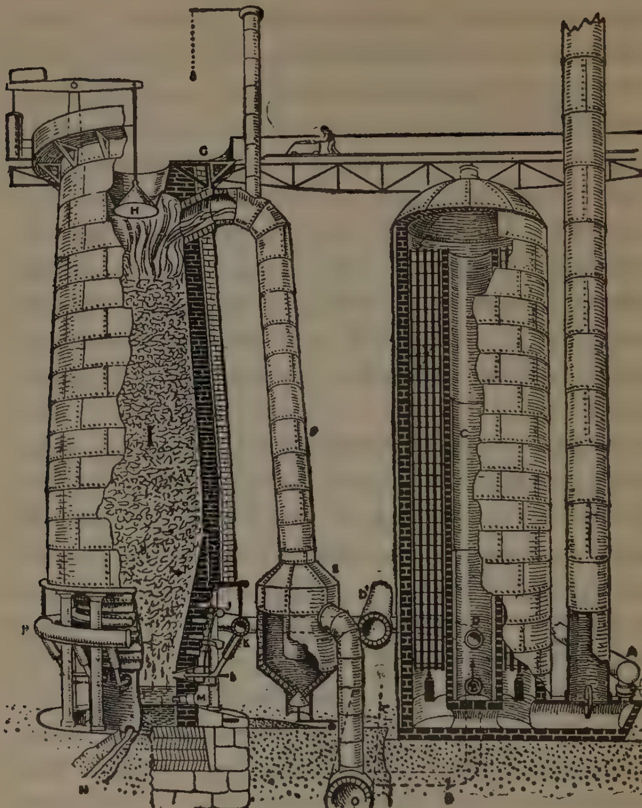
which to choose. Steel in the form that to-day makes nine-tenths of all machinery is a comparatively modern invention, and new metals like aluminium and many useful alloys have only recently been brought into the service of mankind.

In all the story of invention there has been nothing more romantic in its far-reaching influence than the story of steel. Now, steel is a very remarkable substance. You can think of its unending list of uses. It would take a long time to make a list of those that are purely domestic —that occur in every household. It would be impossible to make a list of its wider applications, from biscuit - boxes to battleships, bridges, railways, tunnels, water-pipes. The Larkin skyscraper in New York, the highest building in the world, is going upwards as a colossal steel cage, a steel-framed mountain of masonry rising twelve hundred feet above the street-level; and is it not astonishing that the substance making the bars of this cage that will house so many people on its hundred and ten storeys is practically identical with the substance that made the spring of your watch? You can have steel harder than glass and more brittle, or soft enough to be twisted between finger and thumb. You can cast it in moulds; draw it

out in a flexible wire as slender as a spider's web; stamp it into a thousand forms; roll it into any thickness between a two-foot girder and a leaf like paper; or beat it into any shape you like, from a sword to a propeller-shaft. Though it may not endure like the stones of ancient civilizations, it has many times the strength of stone. It is the only substance known to man that will cut and shape almost every other substance, and the only one that, when suitably treated, is able to cut and shape itself.

This wonderful substance is modified iron, and—fortunately for mankind—iron is a very plentiful constituent of the earth's crust. It occurs in enormous quantities in nearly every part of the world and always in a more or less impure state. One impurity from which it is never free is carbon; and the only difference between wrought iron and the far stronger and more tenacious steel is the proportion of carbon contained in it. The steelmakers' task is first to remove from the iron as many of the impurities as possible, including the *unknown* quantity of carbon, and then to add to the relatively pure metal a *known* quantity of carbon.

The first stage is to separate the metallic



Blast-furnace and Blast-heating Stove
(Partly in Section to show the Construction

A, Cold blast entering stove. B, Gas inlet to stove. C, Combustion chamber. D, Hot blast main. E, Dust catcher. F, Downcomer, carrying off gases from furnace. G, Charging platform. H, Bell for closing mouth of furnace. I, Ore and fuel. J, Water pipes. K, Hot blast pipe. L, Tuyères. M, Slag notch. N, Iron from tap hole. O, Gas main.

iron from the earthy ore by smelting. The modern blast-furnace in which this operation is performed is a veritable tower of strength. Nothing that man has ever made can compare in grandeur with the titanic smelting furnaces. And those who have never been to a region where iron and steel are produced in millions of tons can form no more than the vaguest mental picture of the strange unnatural grandeur such a centre presents at night-time. By day the city of steelworkers is gloomy, barren, and forbidding; the sky is masked in smoke and the earth devoid even of a little greenness. But after dark the steel city is a city of fire. The sky is red and yellow with lurid flame; a hundred furnaces have each their own volcano, now flaring into fierce eruption, now dying to an angry glare upon the night.

The blast-furnaces are great steel towers, lined thickly with fire-resisting material, standing in groups of eight or more in a black wilderness. Around them rise tall chimneys, and strange steel-lattice towers carrying cables from which ore-laden trolleys rush to and fro overhead; and everywhere are great black hills of waste and slag, ever getting higher; and black lakes in the hollows between them, ever getting deeper; and hither-thither crawl the trains of

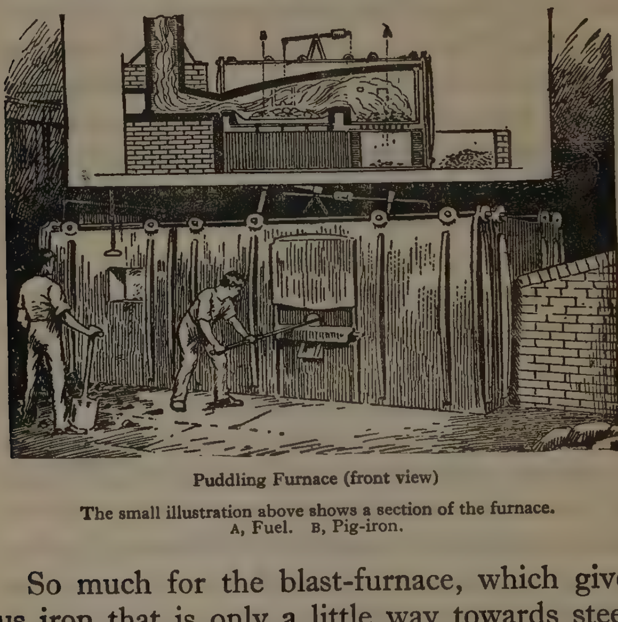
ore on a maze of railway tracks; and by each group of blast-furnaces an open level space with glowing, smoking channels in which the molten iron flows to the countless moulds.

The tower-like furnaces may be a hundred feet high or more, and more than that in girth. The groups are connected by huge pipes with a central furnace called a " stove ", which is not itself used for smelting. The pipes conduct the hot gases from the blast-furnaces to the " stove ", which heats the air for the blast and helps to drive the heavy machinery of the works. Each blast-furnace has an inclined approach leading to a gallery at the top; a most ingenious mechanism hauls up the trucks of ore, fuel, and lime with which the monstrous shaft is continually fed—ten tons at a time, it may be; the cone-shaped lid of the shaft is automatically lowered, the truck is tipped up, and its contents roll down into the furnace. Then the lid is closed again, a tremendous blast of hot air is directed into the burning mass of ore, and the iron, freed from the dross, flows out at the base of the tower in an incandescent river that leads to the myriad troughs in which it cools and becomes " pig-iron ". Meantime, the empty truck has descended the inclined plane to join an ever-growing train of empties, its place on

the tower being taken by a full truck from an ever-diminishing train on a parallel track. And so the cycle continues, day and night, week in, week out, the "pigs" being continually drawn out of the troughs as soon as they are cool enough, to make room for the living stream that flows unceasing from the furnace.

That a blast of air to increase the rate of combustion on the hearth was necessary to release the metal from the dross was known to ironmasters hundreds of years ago. But it was not until the early nineteenth century that the labours of a Scottish workman led to a discovery concerning the blast that may truly be said to have revolutionized the iron-smelting industry. The man was James Neilson, born in 1792, and his study of the ironworks growing up around the city of Glasgow led him to the conclusion that the blast of cold air as then used was extravagant. He believed that a blast of hot air would effect a great saving of fuel, but it was many years before he could prevail on an ironmaster to permit him to apply his theory. At length, however, Neilson was allowed to try his hot blast. The result was that the incredulous ironmasters found that the same amount of fuel operated by the hot blast smelted half as much ore again as the cold blast. Any

science-school student can now explain why this should be so, but at the time it seemed to the north-country ironworkers to be little short of magic. Neilson's application of the hot blast gave an enormous impetus to the industry by lessening the expense of smelting.



Puddling Furnace (front view)

The small illustration above shows a section of the furnace. A, Fuel. B, Pig-iron.

So much for the blast-furnace, which gives us iron that is only a little way towards steel. It does not even give us good iron, the annoying fact being that although the furnace has freed the iron from the ore it has forced it to absorb a number of very undesirable sub-

stances. To get rid of more of the impurities, the ironmaster employs a process that is closely akin to that of the laundry. Just as the washer-woman kneads and rubs the linen in the wash-tub to get rid of the dirt, so is the iron kneaded and rubbed and "washed" in a molten state. The process is called puddling, and it is one of the hardest and most disagreeable operations which have still to be performed by hand. Upon the "bed" of a puddling-furnace are placed several hundredweights of cast-iron "pigs" mixed with coke. The puddler and his mate stir the mixture with a long iron rod until it begins to melt; and as soon as it is liquid the stirring-rod is changed for a strong iron bar with a bent end, called a "rabble", with which the puddler stirs and rakes and squeezes the contents of the furnace. The iron seethes and bubbles, and spurts of blue flame gush from the surface. The more violently the iron boils, the harder works the puddler, every muscle straining to keep pace with the changes that are taking place in the chemical composition of the iron. The end of the "rabble" softens, and he casts it into a trough of water while his mate continues the working with a fresh one. So the exhausting labour goes on until the molten iron, washed clean of the dross and cinder and

freed from most of the carbon and the phosphorus and sulphur and silicon, thickens into a soft spongy mass. It is then broken up into balls or " blooms ", withdrawn from the furnace, and taken at once to a steam-hammer that beats it with gradually rising force, the liquid cinder being squeezed out like water from clothes in a mangle. Indeed, it is literally mangled, for from the hammer it passes to great rollers that still further squeeze and dry it.

The bar of metal resulting from this process is relatively pure iron. It can be beaten into horseshoes or boiler-plates; but it will always remain soft. We have yet to give it the toughness and prodigious strength of steel. We must restore to it some of the carbon that has been so laboriously taken away. The iron must go back to the fire, therein to combine with that degree of carbon as is exactly required to convert it into steel of predetermined quality. In the next furnace, however—it is called a " cementing-furnace "—the iron is not actually melted. Long iron bars are placed in an oven or " chest " and closely surrounded with charcoal, which is almost the purest known form of carbon, the whole being plastered over to exclude the air. The furnace is started and kept burning at a glowing red heat for a week or more, when

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By courtesy of Messrs. Dorman Long & Co., Ltd.

STEEL MAKING

Pouring steel into 10-ton ingot moulds. When the steel has solidified the moulds are dragged off, leaving the white-hot ingots

—if the cementing has gone far enough—it is left for another week to cool. When the iron bars are taken from the chest, they are no longer iron but steel—blister-steel it is called, from the strange dark blisters with which it is covered. The iron has taken up the carbon. And the process is a truly remarkable one, for it is a mystery how solid carbon can penetrate solid iron. Yet that is what has happened in the cementing-furnace, only very unevenly, less carbon being in the centres of the bars than nearer the surface, with the result that the steel is of very unequal strength and hardness. Much has yet to be done to produce steel of really good quality.

Back it must go to the furnace. The bars of blister-steel are cut up and melted in a crucible with intense heat, the carbon thus becoming evenly distributed. This crucible-steel is the finest that can be made, and owing to the great amount of fuel used and the high cost of the crucibles, it is very dear and consequently used only for special purposes. From it the very finest tools and appliances are forged, and it enters into those parts of high-speed machinery in which great strength combined with lightness and durability are called for. Steel must be cut and shaped by steel; and it

is quite obvious that the cutting-tool must be harder and stronger than the object to be shaped. Crucible-steel alloyed with a small amount of some rare substance further to increase its toughness is the metal of which are made the tools that can continue to cut hard-steel masses revolving in a lathe—for engine-shafts, gears, and the like—hour after hour, although they are white-hot.

Metallurgists are continually adding to the number of rare metals which, when mixed with steel in the crucible, increase its adaptability for some purpose or another. There are chromium, tungsten, nickel, aluminium, vanadium, and others which are still in the experimental stage. Little did Benjamin Huntsman, who first made crucible-steel at Sheffield about 1740, dream that one day his secret process would create projectiles that should make armour-plate of no account, or drills to scoop their way through cold steel as though steel were as soft as cheese.

Crucible-steel and the wonderful steel alloys are too expensive for all except the highest uses. For such things as tools and cutlery and most parts of engines and machinery the crude blister-steel from the cementing-furnaces is treated in a cheaper fashion. The bars are bound together in huge bundles weighing

several tons and heated to welding heat—the heat at which they are soft enough to join together. The plastic mass is then taken to a steam-hammer which rains upon it a terrific shower of blows, gradually increasing in intensity and speed. The heat of the hammering is so great that it keeps the "faggot" of steel bars soft, and it soon becomes a homogeneous mass in which the carbon is fairly evenly distributed. The next step is to cut or "shear" the lumps of steel into bars again, to be reheated and rehammered, and according to the number of times the process is repeated the steel is said to be single- or double- or triple-shear, its price and quality increasing with each repetition.

The two processes just described provide only a very small proportion of the world's steel; there is never very much, relatively, of the best of anything. It was Sir Henry Bessemer's method of making steel in a much cheaper way that led to its production by the hundred million tons a year, and so introduced the Steel Age that we now live in by widening the metal's application in a thousand undreamed-of ways.

Henry Bessemer was the son of a French artist who had settled in England. A very prolific inventor, it is related that his thoughts

first turned to steel through hearing that the Emperor Napoleon III of France was searching for a better material for guns than the cast iron then in use. Bessemer did, in fact, make a little steel gun and was permitted to demonstrate its superiority to the French Emperor, who gave the inventor permission to erect an experimental foundry on French soil. But, for the most part, no progress was made until one day it occurred to Bessemer that it might be possible to make an improved wrought iron by the simple method of blowing a jet of air through a vessel of the molten metal, and so burning out all the impurities. Here was a "brain-wave" in which Fortune smiled on the inventor, for he was really working without any sound knowledge of the chemistry of iron to guide him. In 1850 metallurgy in its modern sense was an unknown science; there was then no exact chemical or microscopical investigation of the changing molecules of iron and steel. But it so happened that Bessemer's simple experiment was a startling success. In a few minutes his jet of air had transformed the cast iron into a kind of mild steel infinitely tougher.

Thrilled by the ease and simplicity of his success, Bessemer made experiment after experiment, model after model, until he was satisfied

with a small " converter " in which was a vessel to hold the liquid iron, connected by pipes with an air-box served by a blowing engine. And when the time came to put the apparatus to the crucial test, once again was the inventor favoured by Fortune. He ordered for the purpose a ton of iron, without specifying iron of any particular kind, for he was quite unaware that there were many forms, differing widely in their chemical composition, from which to choose. It so happened that the firm from which he had ordered sent him, by pure chance, just the right kind of iron needed to make the " conversion " in his furnace a success. Any other variety of pig-iron would have resulted in complete failure and would probably have led Bessemer to give up his task. As it was, the ironworkers to whom the inventor passed his steel for testing were astonished at the properties of the new material. It was tougher and more ductile than anything they had ever handled; it could be cut or rolled, hot or cold; made hard or soft at will; and, in short, had all the protean nature of mild steel.

In 1856 Bessemer's process was amply covered by patents, and the leading ironmasters of the country were making terms with the inventor. In a few months he was the richer by £50,000,

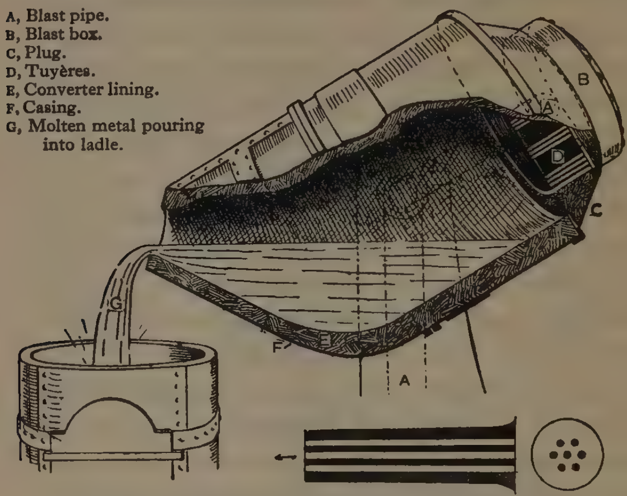
five firms paying £10,000 apiece for the right to make the new metal under his patent process. And in five important ironworks much capital was promptly laid out on the plant whereby this superior metal might be turned out ten times more quickly than steel was made from the blistered bars from the cementing-furnaces and the steam-hammers. But in a very short time—no longer than it took to make the first charges in the new converters—there were five angry and disgusted ironmasters and a puzzled and dismayed inventor.

Henry Bessemer was obliged to face the disappointing fact that in every case the metal run from the converters was rotten and worthless. The explanation came when he resumed experiments with the iron he had first used and found to his delight that the steel produced was entirely satisfactory, while the use of another brand of pig-iron yielded spongy or brittle and useless steel. There was obviously some impurity in certain brands of pig-iron, the nature of which he must discover in order that it might be eliminated, if possible, or at least avoided. So he set practical chemists to work on the samples of steel from the converters —the good sample he had himself made, and the bad samples from the five outraged iron-

masters—and the chemists showed that the bad samples all contained high proportions of sulphur and phosphorus, while his own was low in those substances. It seemed indispensable, therefore, that the ores used for smelting pig-iron for Bessemer steel-making must be relatively free from the harmful elements; and Bessemer, backed by friends, started a steel-works at Sheffield. In a couple of years this works was turning out enormous quantities of the new steel, which quickly began to take the place of cast and wrought iron for heavy things like rails and big engine-shafts and boiler-plates.

When engineers found that the new steel, though it cost twice as much as the cast and malleable iron they had been using, possessed about ten times the wearing qualities, iron-founders throughout the world had to instal Bessemer plant to cope with the millions and millions of tons that were needed. Bessemer's process created a revolution in the iron industry. His invention is without question one of the most important ever given to mankind. Bessemer escaped the fate of so many of his kind and became a very prosperous man. In his own words, he received in the form of royalties "1,057,748 of the beautiful little gold medals issued by Her Majesty's Mint".

In the impressive grandeur of its violence there is no human task equalling the making of Bessemer steel. All the labours of the steel-worker—the melting, the rolling, the hammering of huge masses of metal—are fearful and



Bessemer Converter (partly in section) pouring contents
At the right-hand corner are shown a section and end view of a tuyère.

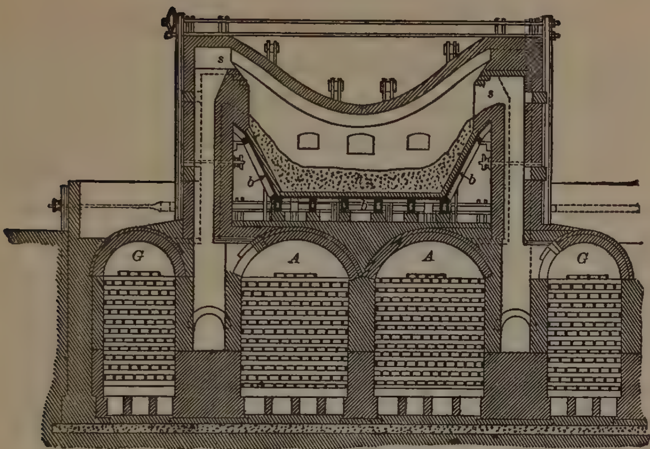
awe-inspiring; but nothing approaches the terrifying fury of the Bessemer converter in blast. The converter is a vessel, roughly egg-shaped, swivelled about its horizontal axis. At the bottom are a large number of air-pipes (called tuyères) connected with the blowing machinery,

while the top is left open. The converter being swung into such a position that the vertical axis becomes the horizontal, the charge of molten iron—which may be seventy tons or more—is poured in through the opening. While the converter is in this position the metal cannot fall to the bottom, but forms a pool lying in the rounded side of the "egg". When the "egg" is turned back to its vertical position the metal, of course, falls to the bottom, where the tuyères are, but it cannot run down these because the air-pressure holds it back. The air tears through the molten metal, burning out the carbon and silicon with terrific fury. Though nothing is added to the melted iron but cold air, the contents of the converter rise to a heat unattainable except in the electric furnace. A huge flame roars from the mouth, and dazzling showers of coruscating sparks dash against the flame-shaft and add to a volcano of indescribable splendour. For ten minutes the inferno grows and roars with increasing violence, then gradually grows quiet. The converter is turned again to the charging position, and a small quantity of melted iron very rich in carbon is poured in. There is another fierce tumult in the incandescent mass, then quiet, while a giant blue plume of flame

waves silently about the mouth of the converter. The steel is made.

Since Bessemer's invention of 1856 there have been many improvements in the science of steel-making. An extremely important modification of Bessemer's process was introduced in 1878 by Sydney Thomas and Percy Gilchrist, whereby it was made possible to use the inferior but very plentiful kinds of iron that Bessemer had found to be unsuitable for steel-making. Thomas and Gilchrist lined their converters with a form of lime that, by entering into combination with the phosphorus in the iron, effectually rid it of that harmful substance. Incidentally they provided farmers with a very valuable fertilizer in " basic slag ", the waste product from their converters.

Another name closely associated with the steel industry is that of Karl Wilhelm Siemens, a German who became a naturalized Englishman. He fully deserved the honour of knighthood conferred on him in 1883, the year of his death, for he was an extraordinarily versatile inventor. Indeed, few men have brought about improvements in so many different industries as Sir William Siemens. His researches in heat and metallurgy led to results that are very widely applied. He was a brilliant electrician, and



Section of Siemens Furnace

Air and gas enter the upright passage from the chambers *A* and *G* on the left. They then pass over the metal in the upper chamber, burning as they go, and leave by the passage on the right. The brickwork in the chambers *A* and *G* on the right take up much of the heat which remains in the gases. The flow is then reversed, and the incoming air and gas now entering on the right become heated by this brickwork. This reversal of flow saves much heat which would otherwise be wasted.

apart from much pioneer work in the construction and laying of electric cables, he built the first electric tramway and invented an electrical thermometer for measuring intense heat. But it was his regenerative furnace that led to the association of his name with a method of steel-making almost as important as that of Bessemer. A regenerative furnace is one in which the burning gases from a central furnace are thrown forward and backwards and directed

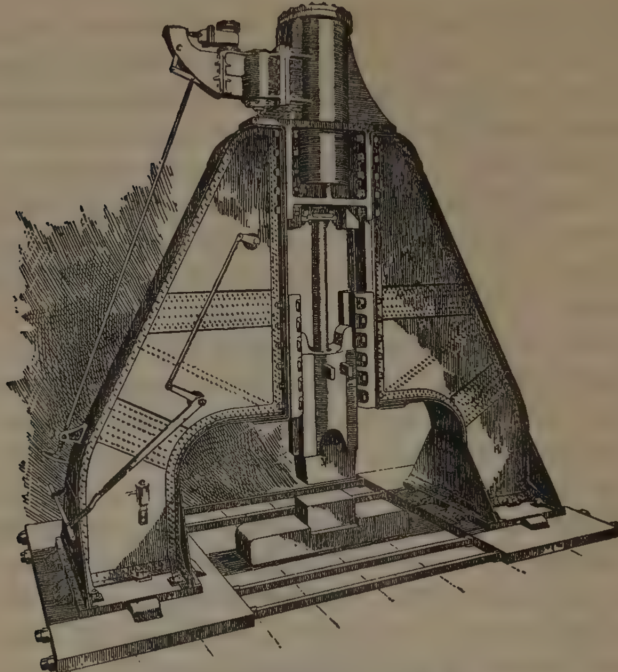
at will to convey their heat to the metal to be smelted by an ingenious system of arches and passages controlled by dampers. The Siemens regenerative furnace was primarily designed for melting the highly refractory materials of which glass is made, more easily and cheaply than in the then existing glass-furnaces. But it soon came to be applied to steel-making.[1]

In every works there is a certain amount of waste. It is, indeed, one of the functions of modern science to see how waste of all kinds, whether of material or of labour, can be avoided or diverted to useful ends. The Bessemer steel-works, for example, soon found themselves burdened by alarming accumulations of scrap—the sawn-off ends of rails, shearings of boiler- and ship-plates—all the oddments of waste material that in the ordinary course would be remelted and re-rolled into usable metal. But it was found that Bessemer steel was very difficult to melt, except by costly and wasteful expenditure of fuel. The new Siemens regenerative furnace provided a way out of the difficulty; and in a short while the Siemens-Martin steel process was in powerful competition with Bessemer's. The Siemens-Martin process consists essentially of a " bath " or crucible of molten iron, heated by a regenera-

[1] A fuller description of this furnace is given on page 75.

tive furnace, into which the scrap Bessemer steel is dropped. In such a furnace the steel is easily melted, and by the addition of a further quantity of carbon a steel is produced which is much superior to the "mild" steel of the Bessemer converter.

This chapter began by insisting on the difficulties under which the early inventors laboured from the meagreness and unreliability of their tools; let us conclude it by a hurried glance at what has been done to equip the mechanic's workshop since Henry Maudsley, the pioneer of toolmakers, gave mechanics reasonably accurate screw-threads, as related on page 53. To this London mechanic of a hundred years ago the machine-made world of to-day owes an infinite debt. It was Maudsley who, by inventing the slide-rest, raised the lathe from the primitive state in which it had existed from time immemorial to its present position as the most important of machine tools. That simple apparatus for holding tools in any desired position against the work revolving in the lathe made possible the boring of a true cylinder and a piston of exactly corresponding diameter, and so gave a great impetus to the manufacture of steam-engines. James Nasmyth, one of Maudsley's many brilliant pupils, invented the steam-hammer in 1839; nine years earlier Sir Joseph



A Modern Steam-hammer, 12-ton size

By permission of Messrs. B. & S. Massey, Ltd.

Whitworth had produced a machine for planing a perfectly even face on a metallic surface. And so came into being these essential tools of every foundry and machine-shop — the lathe, the steam-hammer, and the planing-machine.

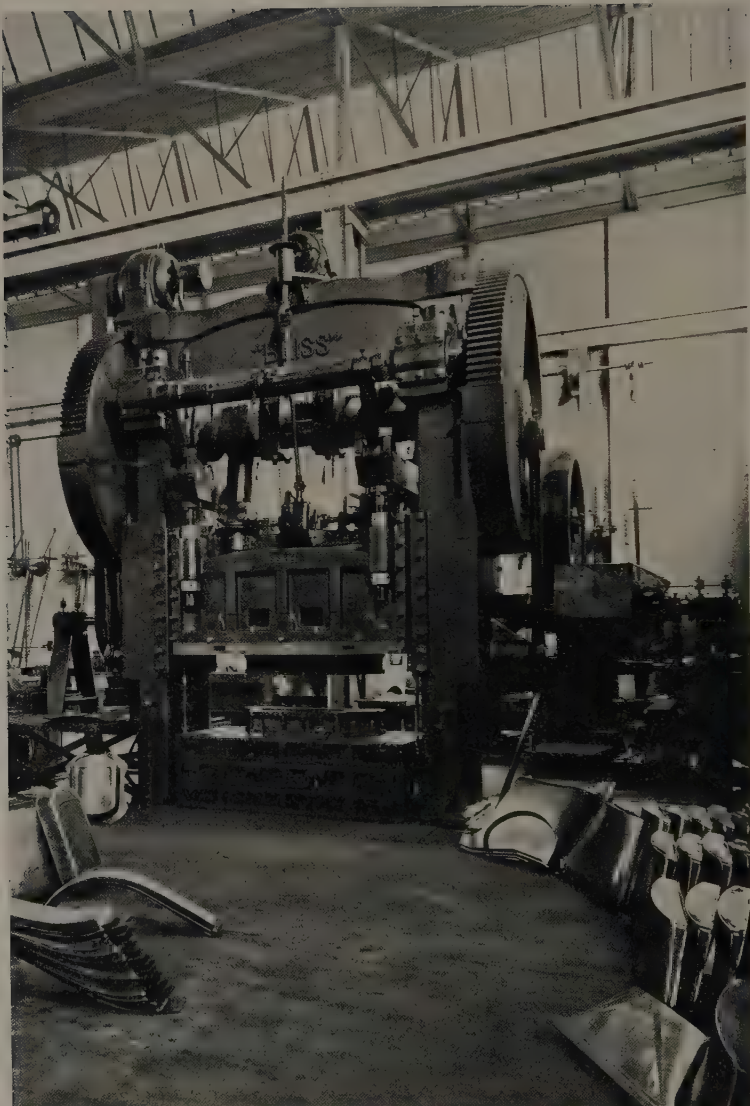
Nowadays, there are so many machines for making machines that it is quite impossible to

speak of more than a few of them. Do you want a crank-shaft for a locomotive? There are the hydraulic presses and the steam-hammers that will shape it for you from a mass of steel. Wonderful appliances, these descendants of Nasmyth's giant, and capable of delivering a punch of sixty or seventy tons as many times a minute, beating the reluctant steel into the required form and toughening it with every blow. And yet so delicate in their adjustment are these stupendous tools that you can put an egg in a wine-glass on the anvil and command the hammer to descend upon it, and yet have your egg and the wine-glass unscathed. Or will you see the great lathe at work turning to perfect precision the rough forging from the steam-hammer—a marvel of complexity, of rigid metal masses and intricately moving parts all directed to the single purpose of paring your crank-axle to an exactly predetermined size? The awkward object revolves and the cutting-tool moves forward, while the steel shavings curl in spirals just like the shavings from the carpenter's plane. A shaving taken from that part, the tool recedes to take up another position where it will pare a shaving from another part; and so it will go on, day after day, machining up crank-axle after crank-axle as exactly alike as

if they had been made in a mould. But they are not finished. There are minute variations that only delicate gauges can perceive, and each crank-axle must be ground by emery-wheels revolving at prodigious speed until they are perfect in shape and size to within a few ten-thousandths of an inch.

And here is a machine for cutting gear-wheels out of solid discs of metal. And here is one that shapes the bevelled wheels for the differential gears of motor-cars. That one cuts slots in the gear-wheels so that they may be immovably fixed, by means of keys, to the axles on which they are destined to revolve; and yonder is a triumph of ingenuity that can unerringly machine to shape internal surfaces of complicated design—even a box-like chamber that no man's hand could reach into to file or scrape, even if it possessed the skill to do so.

There is indeed no end to the thunder and the rattle and the whirr from the machines that are making machines. They roll rails and girders from white-hot ingots; they stamp an unceasing stream of small articles, from the drop-forgings that may become important parts of engines, to toys and bottle-caps. They cut metal plates and electrically weld the pieces into vessels of different shapes; they make rods and tubes



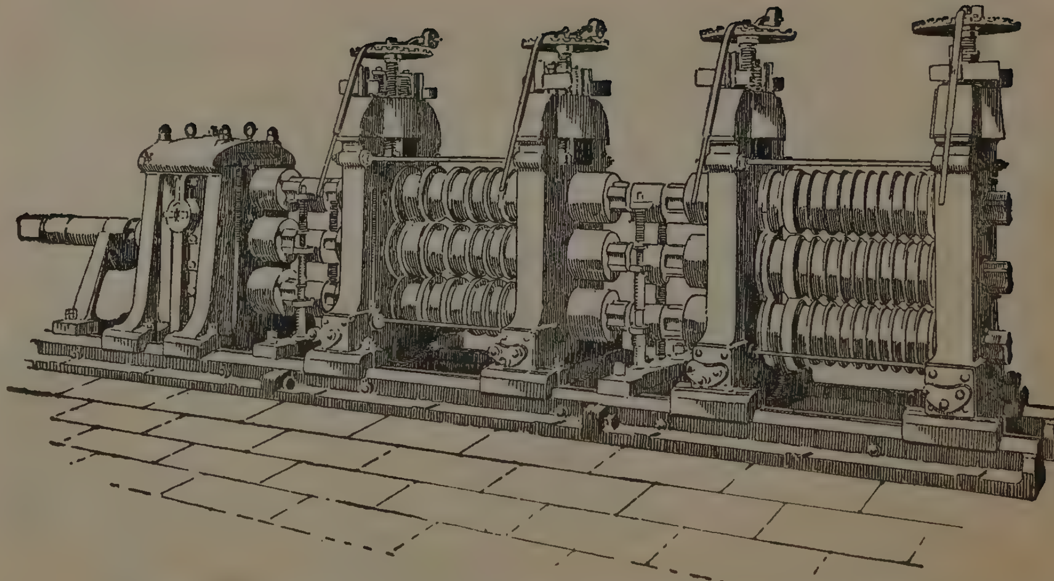
E 126 By courtesy of Messrs. The Austin Motor Co., Ltd.

500-TON "BLISS" PRESS

Mud-wings, tanks, panels, &c., are pressed from sheet metal by this machine

and wires and balls; in short, they will make anything for anything from a locomotive to a watch, and make it far better and far more cheaply than was ever possible by hand. One of the immediate results of the Great War was an enormous impetus to mass production, first of munitions and afterwards of all the commodities required for the restoration to peaceful conditions. An inevitable result was that quality and accuracy were sacrificed to speed, and there arose a fear of a general deterioration in the high standard British and other European engineers had set the world. Fortunately, however, these evil prophecies have not been fulfilled, and engineering experts now claim for British machinery that within the last few years there has been a greater degree of accuracy in workmanship, in the selection and treatment of materials greater care and knowledge, and in technical skill a higher standard than ever before. A contributing factor to this advance has been the imperative demand to meet the increased costs of labour and the shorter hours, necessitating the employment of the most efficient tools, from which the last ounce of output can be extracted.

There is no phase of human enterprise in which progress has been less interrupted than



Rolling-mill fitted with Rolls for Rolling Rounds. (By permission of Messrs. Thomas Perry & Son, Ltd.)

The operations of rolling are begun when the billet is at white heat, and continued until the metal is dull red. The process of producing any particular section is carried out in a number of operations, the approach to the size required being made in a series of steps.

that which has been concerned with the Steel Age. Many men and many nations have helped in that progress—inventive geniuses, industrial leaders of rare courage and foresight, and chemists, metallurgists, physicists. We owe more than we can ever repay to the patient inquirers into the mysteries of pure science, for theirs have been the labours that give us our security—the real mastery over our tireless servants of steel and brass. Is there a bridge to build? Every batch of metal must be tested; each plate, each girder, each rivet must be of known strength, examined by the microscope to confirm its structure, bent and twisted and strained in machines specially designed for the purpose, far beyond the endurance ever likely to be suffered by the material in service. Or would you have a motor-car? If it is built by a good maker, you have an assurance that, though there is not a pound more material in its construction than safety demands, the strength of every part is of predetermined security. Pieces were cut from its vital members when they were being fashioned, and submitted to sterner tests than any a careless driver could apply. Your axles have withstood greater impact shocks than the roughest road will convey, before ever they were built in

the car, for a machine then hammered and hammered and hammered at them, for hours on end, to make absolutely sure of your safety on the road so far as the makers could be responsible for it.

Faster and faster run the machines; not in the air only, nor on the roads, but wherever their wheels are turning, even in the places where we cannot see them. All the while, as a consequence of this increasing speed, the men and women who have charge of them are put under an ever-growing strain. As an example of how surely yet imperceptibly hasten the machines that serve our every want, let me take instances that figured in two machinery exhibitions in London held four years apart. At the exhibition in 1924 there was shown a very beautiful machine designed for sawmills. It made tongued and grooved boards. A man fed it with rough planks, which immediately emerged tongued and grooved and smoothly planed, the shavings being but a thousandth of an inch in thickness. It tongued and grooved and planed the boards at the rate of 300 feet a minute. At the exhibition of 1928 was a similar machine, yet not the same. It turned out match-boards at the rate of 450 feet a minute, or about 23 miles in a normal working day—a gain of 150

feet a minute since the exhibition of four years before. The thickness of its shavings was only three ten-thousandths of an inch. And—mark this—there is now an automatic feeding-table, its speed having grown beyond the power of man to keep it fed with boards.

One very interesting development of steel-making which we cannot overlook has been concerned with the introduction, within the last few years, of a stainless, or rustless, steel. Such steel has now become a commonplace of table cutlery—to the virtual ruin, I am afraid, of the domestic knife-board industry. An ordinary table- or pocket-knife rusts more quickly than an iron nail. This is partly because the iron in steel is more readily soluble in water, partly because steel has a less uniform molecular structure; we may say that its unequal "grains" are more ready to combine with oxygen. The advantages of a steel unsusceptible to corrosion are too obvious to need emphasis, and more than a hundred years ago the great Michael Faraday sought for such a steel and indeed actually found it. He produced it by mixing with the iron a large proportion of the metal chromium.

Chromium is literally the "colour metal", from the great range of colours obtained from

its compounds. Most of our stainless knives are made of chrome steel, a very different thing from the metal evolved by Faraday, which was too brittle to be useful for anything. Yet it is the essential brittleness of steels containing high proportions of chromium that still renders the prospect of a rustless steel for structural purposes a rather dim and distant one. Our rustless steel is really a very poor sort of steel, of low tensile strength, yet good enough to cut our food with. To secure a high tensile strength, all the carbon must be taken out of chrome steel; and to do this involves a very costly and complicated metallurgical process. It is said to cost more than £100 to take the carbon from a ton of chrome steel worth £20. Another disadvantage is that the usual cutting, grinding, or machining lessen or nullify the rustless quality. But — though our stainless knives are sources of irritation when the meat happens to be tough—there are wonderful steels alloyed with chromium and nickel or cobalt, of necessity very costly (although cheapening of the processes will doubtless come in time), that are helping in no small measure to the realization of security in the air. Of such steels are the exhaust-valves of aero-engines made, capable of resisting pitting and scaling under great heat and great strain.

CHAPTER IV

The Age of Electricity

I.—The First Phase

Those who have made acquaintance with the myths of Ancient Greece may remember the story of a graceless youth named Phaeton. He was the son of Phoebus, the sun-god, who used to ride every day through the sky in a chariot containing the sun. One day Phaeton thought it would be a joke to take the sun out, believing that he could manage the chariot as well as his father. So off he set, only to find that the sun chariot was a very difficult vehicle to steer. It darted here and there, and approached so near to the earth that in North Africa it left a trail of burning, sterile sand, and burnt the natives ebony-black. And Zeus, King of the Gods, fearing a worse disaster, hurled a thunderbolt which sent Phaeton headlong into the river Eridanus.

It might be supposed that no one would have mourned much for Phaeton, who was in all

respects an intensely disagreeable young man. But he had some sisters who went to the banks of the river Eridanus and wept and wept for his loss so long and so bitterly that at length the gods turned them into trees, as they stood by the river-brink. But even that did not stop their weeping, for from time to time a yellowish sticky gum oozed from the trees, and this substance the people of that part called *elektron*, after Elektor, which was one of the names of the sun-god. The plain English name for it is amber.

This mythical story of the origin of amber—as a matter of fact, amber is found all over the world—is interesting because it connects fact and fancy in the strange eventful history of electricity. Because it is rare and pretty, people made ornaments of amber thousands of years ago, and the fact that it is one of those substances which, when excited by friction, have a power to attract other substances, led them to suppose that their amber beads and other ornaments had magic qualities and so to value them the more highly. But it was not until a remarkable old gentleman of England began to make experiments with amber more than 300 years ago that any useful deductions were drawn from the phenomenon that was so well known. This old gentleman was Dr. William Gilbert.

He was Court Physician to Queen Elizabeth and her successor King James I, but his duties in that capacity seem to have left him time to pursue investigations which showed that amber is not the only substance which when rubbed attracts light objects, but that the property belongs to the resins, sealing-wax, sulphur, glass, and other substances. Having in mind the Greek name for amber, Gilbert called such substances " electrics ", and he was the first to use the terms " electricity ", " electric force ", and " electric attraction ".

When Gilbert so connected the phenomena he was studying with one of the Greek names for the sun-god, he did not know, any more than the ancients wno invented the story of Phaeton knew, that there is really a very intimate connexion between electricity and the sun; or that, having suspected the connexion, men would one day give the name " electrons " to the particles of electrically-active matter that pervade all things. But Gilbert's deductions were very important, and he is regarded as the founder of electrical science. He found that metals allow electricity to flow over or through them, and that there was another class of materials which resisted or refused the flow, and thus drew the distinction between electrical

conductors and non-conductors or insulators

Another of Dr. Gilbert's discoveries that had a great influence on the later study of electricity had to do with magnetism. He set aside the theory that had been held up to that time that the magnetized needle by which mariners steered was influenced by the Pole Star. The earth, he said, was itself a great magnet; and he conjectured that electricity and magnetism were different manifestations of the same force. He even invented a little instrument in which a magnetic needle indicated by its movements the presence or absence of the small quantities of electricity with which he charged his lumps of amber and sticks of sealing-wax.

If Dr. Gilbert had been a poor and unknown man carrying on his investigations in obscurity, it is quite possible the world would have had to wait for a very long while before any further steps were taken to probe the mysteries of electricity and magnetism. But he was a distinguished physician under the immediate protection of the royal court, and even though he dabbled in black magic there was none dared interfere with him. The result, fortunately for mankind, was a far wider interest in the old gentleman's hobby than usually fell to scientific men in the sixteenth century. It thus came

about that in a short while throughout the breadth of Europe there were many other old gentlemen hard at work rubbing amber and glass and sealing-wax and brimstone. Of course they discovered interesting things about frictional electricity. They found, for instance, that the kind of electricity produced by rubbing glass was not the same as that produced by rubbing amber or sealing-wax. It was not until much later that the one sort was called positive electricity and the other negative; but they very soon learnt that electrified bodies attract unelectrified bodies until they have charged them with their own electricity, when they repel them.

Having discovered the twofold nature of electricity, the early investigators had moved an important step forward. Then a man named Otto von Guericke invented a machine for exciting electricity by rapidly revolving a ball of sulphur against which the inventor held his hand. The next step was another machine in which both the rubber and the exciter were mechanically operated, and the introduction of an iron tube to conduct the electricity made it possible to get a spark from it. After this, experimenters discovered the very important principle of electrical induction; which means, in the simplest words, that an electrified body

excites or "induces" electricity in a neighbouring body.

Perhaps we are going a little too fast for such of my readers as do not clearly understand the first principles which govern all electrical manifestations. Of course, if the force we call electricity had been made of visible stuff—you cannot have any kind of force without material to make it from—man would have learnt to investigate it much sooner than in fact he did. It is not necessary for us now to retrace all those slow and doubting steps that have led to the Age of Electricity, though some of the "milestones", as we may call them, have so much of interest that we shall want to revisit them. For the present, just try to think that *everything*—the sun and stars, you and I, the food we eat—consists of electrified particles. Now try to grasp the twofold nature of these particles. Whether there are actually two sorts of electrical particles, or whether there is only one sort but two states of that one sort—one active, as it were, and one sleeping—does not matter here. The unmistakable fact is that there are two electrical states or conditions, the positive and the negative.[1]

[1] This is much the safest. I was going to say something of electrons; but if Professor Eddington cannot make them intelligible, they are best left alone. Anyhow, you may rub shoulders with the electron theory if you get as far as the chapter on The Age of Wireless.

If you took a bar of iron and held it in the fire, or rubbed it vigorously, or beat it quickly with a hammer, it would be hot to the touch of your hand. If you stood it in a pail of icy water, it would be cold to touch. And if you took a hot bar and a cold bar and held one in each hand, the hot one would lose heat and the cold one would gain heat until both were the same temperature as your hands, when you would say they were neither hot nor cold. In other words, you are sensible of temperature only when it is greater or less than the temperature of your skin. In exactly the same way, electricity makes its existence felt only when it is present in one body in greater proportion than another. There are many ways by which we can force the electrical particles in a body to a state of greater activity than in surrounding bodies, or let us say in the earth; heat, friction, chemical action are some of them. You can say, if you like, that we can force electricity out of one body into another just as we can force heat into a thing by taking it out of something else. When we have done that, there is obviously a difference of electrical level or balance between the two bodies. Electricians speak of it as " potential " or " difference of potential ", and it is the explanation of every electric current

or discharge. Before we can get any sort of electricity—whether from a thunderstorm or the battery that works an electric-bell—we must first attain this state of electrical inequality in two bodies. The thing which contains the greater quantity of electrically-active particles compared with the earth is said to be positively electrified, and the thing that contains the lesser quantity is negatively electrified.

There is a peculiar quality of these two electrical states, and that, as doubtless you know, is what we may call their mutual antipathy. It is most tersely and exactly expressed in the phrase " Like repels like and attracts unlike ". Every positively-electrified body repels another positively-electrified body; every negatively-electrified body repels another negatively-electrified body; but a positively-electrified body and a negatively-electrified body attract one another. Let us take an example from the thundercloud, but first of all we must have clearly in mind the fact that work of some kind is necessary to create an alteration in the electrical level of two bodies—in other words, their " difference of potential ". A very simple comparison would be the behaviour of water in a U-shaped tube; the water will maintain the same level in both arms of the tube unless

you do something to alter the level. Doing something, no matter what, implies work. You can alter the level of the water in one arm of the tube by working the muscles of your mouth —by sucking to extract the air so that the water will rise—or you can work the muscles of your fingers to push a piston in one arm of the tube, but as soon as you stop working there will be no difference in the water level in the two arms. To carry the comparison a step further, suppose you turn the U-tube upside down. There is still no difference in level in the two arms, because the water has run out, leaving both empty. It is exactly the same with electrical level. Suppose that we had electricity in the U-tube instead of water; the quantity in each arm would remain the same until, by doing some kind of work, we put more into one arm by taking some from the other. Until we did that, we should express the level as 0. We should say there was no electrical potential or difference. But as soon as we had done something that altered the level in the two arms there would be a difference of potential. On the higher side we should have the positive electricity, for which the plus sign (+) is always used; and on the lower side the negative electricity, which is expressed by the minus

sign (—), because it is less than the level, which is 0.

To return to the thunderstorm, what is it that makes the lightning? Clearly, work is necessary, and in this case the work is done by the sun, which is constantly creating a difference of potential in the clouds. It begins when the moisture is drawn from the earth into the sky; it continues with every alteration in the temperature of the air-currents that weave the lovely cloud patterns. It possibly culminates in an alteration in the size of the drops of water forming them, big drops, little drops, drops as fine as mist. And it must happen, sooner or later, that one cloud or another becomes so saturated with positive electricity that its capacity to contain more reaches vanishing-point. To put it another way, the electrical charge is sufficient to overcome the resistance of the surrounding air, for there is not really a limit to the capacity of a cloud. There is a difference of potential between it and the neighbouring clouds, or the earth. The positive charge bursts through the intervening air-space to restore the electrical balance, causing the gigantic electric spark we call lightning.

It was the illustrious Benjamin Franklin, the poor American boy who from printer's appren-

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A FLASH OF ARTIFICIAL LIGHTNING

Energy is stored in a generator and discharged in a blinding flash lasting a few millionths of a second

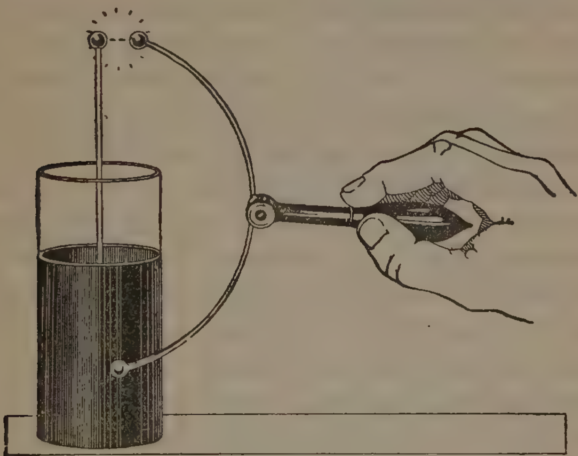
tice became a brilliant philosopher and statesman, who first proved that lightning and artificial electric sparks are electrical manifestations of the very same kind. Doubtless you have read of Franklin's famous experiment with a boy's kite in a thunderstorm in 1746. The kite had an iron point, and a key was tied to the end of the string, and also to a silk ribbon which Franklin held in his hand. The string, wetted by the rain, became a conductor which led the electricity down to the key, and Franklin could obtain sparks and charge a Leyden jar from it. The lightning-conductor that protects high buildings by providing a path down which the lightning may easily pass if the building should be struck was a direct outcome of Franklin's experiment. Franklin also showed that the lightning-conductor had a second but equally important function in protecting buildings. The dangerous thunderclouds, of course, are those that, being positively-charged, have a high difference of potential with the earth. The negative electricity in the earth finds an easier path by way of the lightning-conductor than through the air, and rushing upwards helps to restore the electrical balance.

We may follow the thunderstorm a stage further before we finally disperse the clouds.

They will help us, I think, to grasp more clearly the significance of an invention that came into being a little while before Franklin made his kite experiment. The sun stimulates the particles of electricity that manifest themselves in a thunderstorm; the clouds collect and store them—one cloud the positive particles, and another the negative, the air-space between the two clouds for a time separating or " insulating " them. The clouds act as electrical " condensers ", that is, as vessels in which a large quantity of electricity can be stored in a smaller space than it would normally occupy. I have said that Franklin connected his kite-string to a Leyden jar. Now, the Leyden jar is a simple but very efficient type of electrical condenser, an apparatus for storing in a small space a considerable quantity of electricity. Franklin's jar repeated on a small scale all that had been going on in the clouds from which his kite-string conducted electricity.

The invention of the Leyden jar—the first electrical condenser—was the outcome of an unexpected shock that befell poor Cuneus, a student of Leyden University in 1746. The story is that Cuneus, attempting to electrify some water, filled a glass bottle into which he inserted an iron nail that he intended to hold against

the conductor of his electrical machine. All went well until, in taking the bottle away, Cuneus accidentally touched the conductor with his free hand. Then Cuneus received the shock of his life and dropped the bottle very quickly



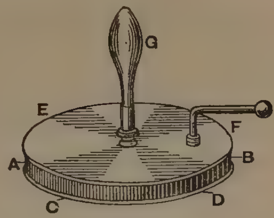
Discharging a Leyden Jar

His master, a peppery professor named Musschenbroek, was angry and sceptical. He as good as told Cuneus that his excuse for the broken bottle was too poor. Was not glass a non-conductor of electricity? He would show Cuneus. So he took another bottle and repeated the experiment, and we may think that the student had some satisfaction in the sight of

another broken bottle and a thoroughly scared professor. "Not for the imperial crown of France," cried Musschenbroek, "would I make the experiment a second time!"

It was not electrified water that gave Cuneus and his master electric shocks, but the fact that they had unknowingly hit upon a means for the storage of electrical energy on the principle that an electrified body induces a charge of electricity in a neighbouring conductor when the two are separated by a non-conductor. In the case of our thunderclouds, the air-space between them was the non-conductor, or dielectric as it is called; in the case of the Leyden jar, the glass was the dielectric separating the positive and negative charges, which rushed together through the bodies of the experimenters, who were in electrical contact with the earth.

The principle of the Leyden jar was a very important discovery because it made possible the study of electricity in larger quantities than had before been available. Experimenters set to work to improve the devices by which electricity could be excited, and Alessandro Volta—whose name is recalled whenever electricians refer to electrical pressure—was one of the most famous of such experimenters. Volta was born in 1745 and died in 1827, his long lifetime wit-



Electrophorus

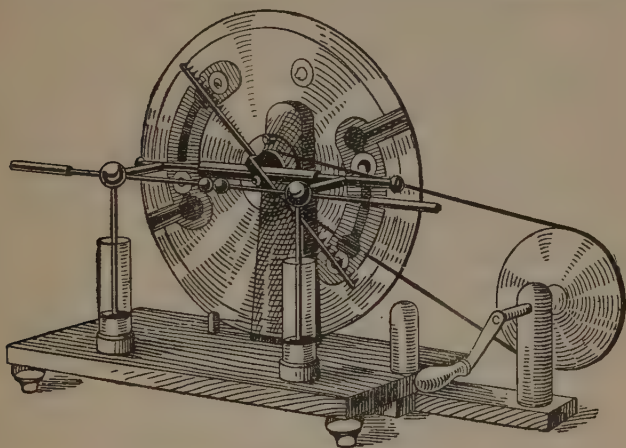
nessing enormous progress in electrical science, to which he contributed a great deal. One of his inventions was the electrophorus, or "electricity-bearer", a simple instrument for inducing small charges of electricity (see diagram). A circular cake of wax AB was cemented into a metal tray CD to which was fitted a detachable metal cover EF with an insulated handle G. When the cake of wax was vigorously rubbed with silk or fur it became electrified, just like von Guericke's ball of sulphur. Then the metal cover was placed upon the wax, and that also at once became electrified by induction. So did the tray in which the wax rested. Static electricity behaves somewhat like a swarm of bees, in its manner of collecting, crowding upon the outside of a conductor; so that when the cake of the electrophorus was negatively electrified, positive electricity "swarmed" upon the surface nearest to it—the top of the tray on which it stood and the bottom of the cover which stood upon it. The surfaces farther away, that is to say, the bottom of the tray and the outside of the cover,

would then be negatively electrified, since like attracts unlike and repels like. When the cover was removed by lifting it by the insulated handle, the separated positive and negative charges rushed together.

Volta's electrophorus was a very feeble electrical machine compared with that invented by James Wimshurst about forty years ago. The Wimshurst machine has two or more glass plates to whose surfaces there are fixed wedge-shaped strips of tinfoil. These serve as collecting-points for the electricity in the plates. When the plates are rapidly revolved—in opposite directions—close to metal collecting-combs connected with Leyden jars, the little electrical charge imparted to each strip of tinfoil is picked up by the collecting-combs and quickly multiplied. The conductors soon become strongly charged, one with positive, the other with negative electricity. In this way the machine produces a flood of electricity not by friction, but by induction, and tremendously powerful discharges can be drawn from it.

Perhaps we may pause to ask ourselves what we mean by that phrase " tremendously powerful discharges ". Well, setting matter in motion —disturbing its molecular rest—at a very rapid rate. Comparatively, of course. We are apt to

use that big word "tremendous" much too loosely. Tremendous in quantity, or in force—which—or both? are fair questions. In the case of a discharge of electricity generated by a Wimshurst machine, the force or *pressure* is



Electrical Machine

sufficient to perforate glass and to render incandescent the particles of the gases of the atmosphere in a 15-inch spark. Well, that is a tremendous electrical pressure compared with that used to light houses and run factories—about ten times as much; but a very trivial pressure compared with the discharge in a lightning flash. Yet the actual *quantity* of elec-

tricity in the Wimshurst discharge is really very small. If you blow into a paper bag, you can confine a little carbon dioxide from your lungs; and you have then a reservoir of gas which you can liberate gently and evenly so that it will play a note on a reed for some seconds. But you can also beat your hands against the bag, and the "air", expelled under high pressure, disturbs the surrounding air with such violence that it strikes on your ears as a loud bang. Clearly, we can measure the carbon dioxide that comes from the paper bag in two ways. The quantity and the pressure or velocity with which it issues forth, which may be almost imperceptible, when it merely leaks out, or fairly rapid, as when we gently press, or very high, as when we bang it.

So it is with electricity. But up to Volta's time, though men could stimulate and separate the two electrical qualities, and even store them up for a time, they could only let them out again with a bang, as it were. Say, if you like, that they had not yet learnt to tame electricity. It was left to Volta to make two very important discoveries: the first, that electricity could be stimulated by chemical means as easily as by friction or induction; the other, that it could be made to flow evenly through a suitable con-

ductor in a closed circuit. Volta's pile, as his invention was called, gave the world the first electric *current*—electricity flowing in an appointed course, as the stream of water flows in its channel. It is the same electricity, of course. The stagnant pool, the trickling brook, and the mountain torrent are all water.

Volta's invention was the outcome of the strange behaviour of some frogs' legs that a distinguished professor of Bologna, Dr. Luigi Galvani, was going to have for his supper one evening in 1780. They were put on the same table as an electrical machine, and an assistant—possibly thinking that was not the right place for them—touched them idly with a piece of copper wire. Each time he did so the frogs' legs kicked violently. This set Galvani and Volta both thinking. They agreed that the kicks were electrical, but they thought of different reasons for them—and both thought wrong. Anyhow, Volta's thoughts had a practical issue in his "pile", or battery—the forerunner of all the batteries invented since his time. It was literally a pile, made of alternate discs of copper and zinc, each pair being separated by a piece of flannel dipped in acidulated water.

The galvanic or voltaic battery—Volta's is the

name to be remembered—produces electricity because it involves an exchange of heat—or work—between the three parts composing it. Whenever two metals in electrical contact are slowly burnt up at an unequal rate, electricity passes from one to the other, creating a difference of potential between the two and maintaining it so long as the chemical changes involved in the burning continue. In Volta's pile, the acid and the zinc attack one another, just as oxygen and fuel attack one another to make fire, electricity is pushed out of the zinc discs on to the copper discs through the water, and out of the copper discs back to the zinc discs through the connecting wire. It is producing an electric current. The energy of the combustion of the zinc and the acid—the work it is doing—finds its inevitable outlet in two ways; partly as heat, partly, as I said just now, in causing a difference of potential. Electricians speak of the energy as E.M.F. It is electromotive force.

A piece of zinc and a piece of copper immersed in dilute acid and connected by a wire form a single cell or " couple ". Two or more cells connected together form a battery. The strength of the current flowing is in direct proportion to the number of cells; that is to

say, the difference of potential between the positive and negative poles of a battery of six cells is six times as great as that between the poles of any one of its cells. So, you see, by the beginning of the nineteenth century experimenters had succeeded in partly taming electricity. They could turn it off and on at will. And you must understand that the amount of electrical energy at their disposal depended on how much fuel they were prepared to burn. Zinc being a very expensive fuel, they could never afford to make very much of it.

There are endless forms of batteries, and they are used for an infinite variety of purposes in which a small difference of potential is required. Indeed, there is a vast range of small, highly-sensitive electrical appliances, for which an intermittent current is required, that are best worked by batteries. But whatever the type, they all work on the principle just explained. But there is another kind of battery in which heat—itself a form of motion—is used instead of chemical action to produce electromotive force. It was while experiments were being made with this kind of heat battery—it is called the thermoelectric couple — that it was discovered that its action was reversible. And that, in turn, led to the discovery that most

batteries could be made to work backwards.

That discovery was a tremendously important step in electrical science. It involves the principle of electrolysis, which is the electrical decomposition of water into its constituent parts of two atoms of hydrogen and one atom of oxygen. Every electric current stimulated between two metals immersed in liquid tends to create a phenomenon known as polarity or polarization. The hydrogen gas liberated from the water collects around the positive pole and sets up a current on its own account, but in the direction opposite to the current flowing through the liquid from the negative pole. Now, that is a great disadvantage in a battery for generating electricity, but it is highly useful when we want a battery to act as an electrical condenser. We can pump electricity in, and keep it stored up with little loss until we want it again, when it will come out—backwards. It is like a twisted string, unwinding in the reverse direction.

Thus there came into being storage or "secondary" batteries. How important a part such batteries play is obvious when we remember that there is hardly any electrical generator that is not made to set aside some part of its current for storage, to be used when it is inconvenient to run the generator itself. Every

motor-car carries accumulators. The stored electricity starts the engine or works the lamps. In fact, there is a type of motor-bus—the petrol electric—in which the sole purpose of the motor-engine is to drive a dynamo that charges accumulators that give current to motors that in their turn drive the road wheels. It seems a roundabout method, but there are particular advantages that make it worth while. The same principle is applied to some of the self-contained rail motor-cars that run on branch railways.

Electrolysis (the awkward word is really not as bad as it looks; it came from the Greek *lysis*, a loosening, because it had loosened the bond that holds together the atoms) has a very important application in electroplating and electrotyping. There are many liquid bodies besides water that undergo electrical decomposition. If you put into a jampot water in which a few crystals of sulphate of copper were dissolved and inserted therein the copper wires from a battery, you would notice in time that the wire from the positive pole was getting thinner, while that from the negative pole was becoming neatly plastered over with new copper. The current is splitting up the sulphate of copper into its constituents of copper and sulphuric acid. The copper, being positively electrified,

streams to the negative wire, while the sulphuric acid, being negatively electrified, collects at the positive wire. It is obviously not a difficult matter to substitute for the negative wire in the jampot an object coated with an equally good electrical conductor that will take upon it the dissolved copper. That is electrotyping. It is used for making seamless copper tubes, the metal being electrically deposited upon rods, from which the tubes are drawn off as soon as they have reached the desired thickness. It is also the method by which the blocks for printing illustrations in books and newspapers are made. The master discs from which gramophone records are stamped by thousands are electrotyped in the same way on the soft wax matrix on which the original sound impulses are recorded. Salts of other metals besides copper can be electrically deposited, gold or silver or nickel. Electroplating only differs from electrotyping in that the metal is deposited not upon a detachable mould, but actually on the surface of the object to be plated—say a teapot or a sham half-crown.

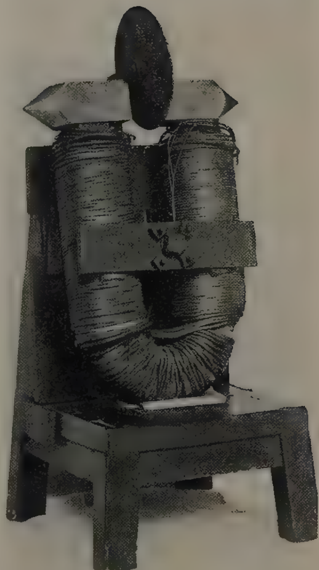
There is one other application of electrolysis which has a narrower and more scientific use. It is a measure of electricity. The amount of water which a current can decompose in a given

time is directly proportional to the strength of the current. Twice as much current will decompose twice as much water in a minute or an hour, or—what is the same thing—the same quantity in half the time. In measuring electricity, there are three things which have to be taken into account. There is the current, expressed in amperes, which may be compared to the rate at which water flows through a pipe—that is, the number of gallons issuing in a given time. Then there is the electrical pressure or difference of potential—the electromotive force that is like the pressure that forces the water through the pipe. This is measured in volts—in honour of the great Volta. Effective electrical energy is very much like effective water-power, for both depend on quantity and pressure. The illustration of the fire-hose is a good one. Suppose a naughty boy stuck a pin in a fire-hose while it was working; the result would be a little jet of water that the boy could stop with his finger.[1] Suppose, further, that the fireman retaliated by turning the hose on the boy; the result would be a boy knocked over. Yet there would be no alteration in the pressure of the water; it is the quantity of water passing through

[1] I have a vague idea that fire-hoses do not mind pins, but perhaps the simile may pass!

the two orifices that makes the difference.

The third factor required in measuring electricity is the resistance in the circuit. The best electrical conductors offer some resistance, just as pipes offer resistance by friction with the moving water. The electrical resistance is not frictional, but the parallel will pass. This electrical resistance is measured in ohms, from the name of the man who established the law that if we can measure any two of the electrical factors —amperage, voltage, or resistance—we can calculate the third. The ohm is a standard measurement, being the resistance offered to the electric current by a thread of mercury of fixed length. One ampere is the current that one volt will drive through one ohm. It is customary to speak of electrical power as of so many watts, the watts being arrived at by the very simple method of multiplying amperes and volts. Thus a tenth of an ampere at 500 volts, one ampere at 50 volts, and ten amperes at 5 volts would all give a power of 50 watts. A knowledge of the meaning of these terms is essential before we can expect to understand the electrical marvels that arose from the genius of Faraday. Let us have a new chapter for the mighty power this genius set to man's service.



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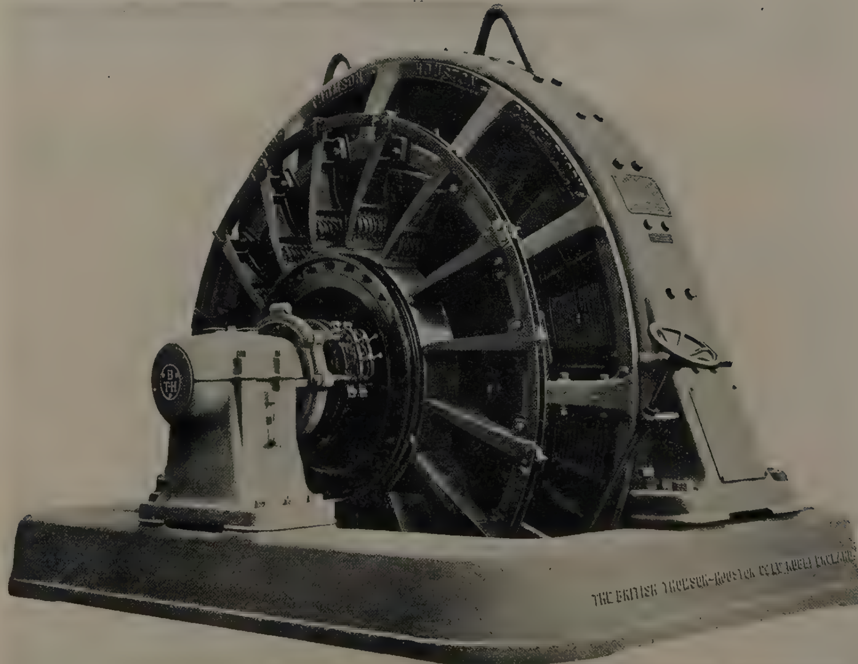
By courtesy of the Editor of the *Illustrated London News*

FARADAY'S ELECTRO-MAGNET

Now in the possession of the Royal



By courtesy of Messrs. The British Thomson-Houston Co., Ltd.

MODERN 550 KW. DIRECT-CURRENT GENERATOR

It has sixteen poles and is used for lighting

CHAPTER V

The Age of Electricity

II.—The Giant Harnessed

The modern phase of the Age of Electricity dates from a hundred and ten years ago. The discovery that unlocked the door to all the wonders revealed in that century was made by a scientist of whom very few outside the ranks of students have ever heard. He was Professor Oersted, of Copenhagen, and his discovery gave a clue to a long-suspected secret. Since Franklin's time investigators had wondered whether there might not be a close relationship between electricity and magnetism; there was an obvious likeness between some of the effects of both. But it was left to Oersted to prove the connexion in 1819.

Oersted passed a current through a wire running north and south above a swinging compass-needle, but not actually touching it. The needle moved and tried to set itself at right angles to

the wire. As soon as the current was shut off, the needle resumed its north and south position. When the current was reversed, the needle again swung to a position at right angles to north and south, but the movement was in a contrary direction. Oersted found, moreover, that when the current was carried under it, the needle moved to the side opposite to that to which it moved when the current was carried over it; and that if the current was carried at right angles to the needle, there was no movement of any kind.

Perhaps this sounds rather complicated. The really important thing is that the discovery opened the way to the study of electro-magnetism and made possible the invention of the electric generators and distributors of our own time. The telegraph, the telephone, the motor-car magneto, the dynamo, the current transformer, the electric motor—all are children of Oersted's experiment. Its significance, one hundred and ten years ago, lay in the revelation that outside the conductor of an electric current there are lines of magnetic force acting crosswise to the direction of the current. The current has its own magnetic field and its own lines of force, just as a magnet has.

What are lines of force; and what is a mag-

netic field? I am afraid I cannot give you a really satisfactory answer, but I can help you to an understanding of some of the ways in which magnets behave. You know, of course, that any magnet—the little needle of a compass, for instance—is influenced by the magnetic force of the great mother-magnet, the earth. We say that a swinging magnet is acted upon by the earth's magnetic field, and that it sets itself along the lines of force of that field. You know, also, that if you introduce a magnet within a foot or so of a swinging compass-needle, the latter takes up quite a different position. Obviously, it is acted upon by the magnetic field of the magnet.

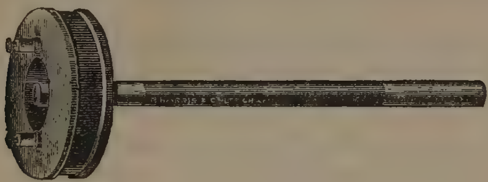
It is very easy to demonstrate the existence of the lines of force in a magnetic field; tens of thousands of children have done this. They hollow out a piece of wood to hold a bar magnet, so that the upper surface of the magnet is flush with the wood. They then put a piece of paper over the magnet sunk in the wood and dust it with fine iron filings. The filings within reach of the magnet arrange themselves in a definite pattern. Every one of the filings has become a magnet, having its north and south poles, and the pattern is really a map of the lines of force of the magnet, in a particular

plane of its field. The "field" really extends in every direction—up and down, as well as sideways. And we see, also, from this very simple experiment that, as in electricity, in magnetism like repels like and attracts unlike.

The great Sir Humphry Davy once said: "My best discovery was—Michael Faraday." Like so many great inventors, Faraday was a poor boy. He was turned upon the world, with little or no schooling, at the age of twelve. That was in 1813, when he became errand boy to a London bookseller who afterwards took him as apprentice. When he was twenty-one he sent to Sir Humphry Davy some notes he had made on lectures delivered by Davy at the Royal Institution. The effect was sensational; one night the splendid carriage of the great scientist stopped outside Faraday's humble lodging, and a liveried footman presented a note bidding the bookseller's apprentice wait upon Davy next morning. Faraday's gratitude knew no bounds when Davy, by making him an assistant in his laboratory, started him in earnest on the scientific career that was destined to have a mighty influence on the life of the ensuing century. It was in 1831 that he pushed Oersted's discovery a stage further. Oersted, you remember, had discovered that an electric current

induces magnetism. Faraday showed that magnetism can induce an electric current.

That discovery established the principle of the dynamo. In the fewest possible words we will try to explain what is meant by induction by magnetic fields. When a coil of wire is at rest in a strong magnetic field, nothing happens. But if by moving the coil or altering the strength of the field there is any change in



Current induced in a Coil by the Motion of a Magnet

the number of lines of force passing through the coil, a current flows in the coil just so long as the change is going on. An increase in the number of lines of force gives a transient current in one direction; a decrease, a transient current in the opposite direction. Let us put it another way, having clearly in our minds what is meant by the lines of force in the magnetic field.

Suppose we have in one hand a coil of wire, the ends of which are connected, thus forming a closed circuit, and in the other hand a bar

magnet, and that we bring the two together, passing the coil over the magnet. The movement of the coil cuts across the lines of magnetic force, and that sets up a transient current in the coil, the electromotive force varying according to the number of turns in the coil—that is, the number of places in which the lines of force are cut—and also the speed at which the coil is moved. And if we now withdraw the magnet, a reverse current is induced in the coil, because the lines of magnetic force from the pole of the magnet are ceasing to be present within it. The same thing takes place whether we move a coil through the field of a magnet or move the field of a magnet through a coil.

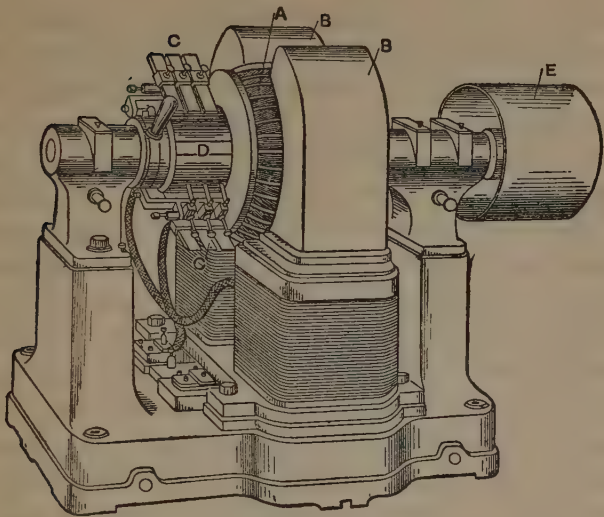
Faraday made a little machine to illustrate this principle in order, so it is said, that he might more easily demonstrate it to his young wife. He was a very delightful young man—indeed, he never lost the charm that, apart from his brilliant genius, made him sought after and loved by all—and she a delightful young woman. Think of that young couple—he was thirty and just married—poring together over the new toy. It was the first magneto-electrical machine. Faraday could not live to see millions of direct descendants of that magneto igniting the gas that moves the endless surge of traffic on the roads; he died

in 1867; but they are truly children of the machine he invented that he might show his wife how a magnet and a coil of wire made an electric current.

Faraday's magneto was in essence the first dynamo also. Improvements did not come very rapidly, because for years to come it did not occur to people that electricity was of practical use. You see, it was interesting to scientists, who were glad enough to have the means of making larger quantities to study. But the age of steam-power was only dawning then; there were no cables for transmitting current, there were not invented the lamps by which electricity might give light, nor the complicated machines by which it might be turned again to power. One of the first improvements made in the dynamo was the strengthening of the magnetic field by furnishing the revolving coil—called the armature—with an iron core. Then different methods of winding the armature were introduced. Ernst Werner Siemens, a brother of the Karl Wilhelm Siemens whose acquaintance we made in the chapter on The Age of Steel, had a good deal to do with the development of the dynamo. In 1856 he invented a particular kind of armature winding and a type of commutator—to commute means

to change, and a commutator is a device for changing the oscillating or to-and-fro surging of the electricity into a current flowing in one direction—and so built the first dynamo giving a continuous current. Another great step was made in 1863, when a man named Wilde obtained much better results by using electro-magnets instead of steel magnets to produce the field in which the armature moved.

However much they differ to look at—and there is a bewildering variety of forms — all dynamos are the same at bottom. Three things are always essential. There is the armature in which the currents are induced—this is generally a ring or drum having a core composed of many pieces of soft iron, and bearing a number of coils, each composed of many turns of wire; there is a strong magnetic field provided by the field magnets; and thirdly, means for rapidly rotating the armature within the field. Sometimes the armature is stationary and the field is made to revolve. The wires on the armature are connected to a system of copper bars from which the current is collected by brushes that press against the bars. If we are satisfied with alternating current, we take it straight to the switchboard; but if, for one reason or another, we require a direct—that is, a continuous cur-



The Electric Dynamo

The armature A, which carries the wires, is rotated between the magnets B, B by a belt which passes over the pulley E. The magnets are wound with wire round which the current flows. C, C are the brushes by which the current enters and leaves the armature. They press upon the commutator D.

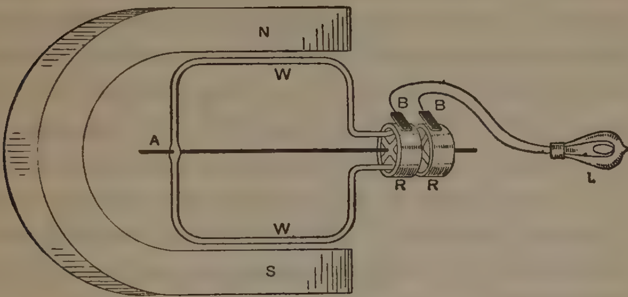
rent—we must interpose a commutator between the armature bars and the collecting brushes.

I am not sure that we are yet in a position to grasp the very important distinction between alternating and direct currents. It is not difficult to see that as the wires in the coils fly round across the intense magnetic field, each of them becomes, one after another, the seat of induced currents; or that each wire adds its own effect

to that of its neighbour, until the accumulated result is led to the point where it is collected by the brushes. To understand more clearly the oscillating nature of the current, try to imagine yourself in the position of a wire on one of the armature coils revolving between two field magnets of opposite polarity. Modern generators have multi-polar fields of many magnets, but for simplicity's sake we will assume two. Very well; pretend that as you are turning round with the armature you have the sensation of intense heat as you cross the field of the north or positive pole, and a sensation of intense cold as you cross the field of the south or negative pole. That must happen in every revolution of the armature—as you go up one side and down the other. If that makes you think of Oersted's experiment with the compass-needle (p. 113), the difficulty is done with. We know that wires crossing a north magnetic field and those crossing a south field possess opposite directions of induced currents. Clearly, therefore, all the wires on the armature—tens of thousands of them—in turn undergo a reversed direction of their induced currents as they pass from one magnetic field to the next.

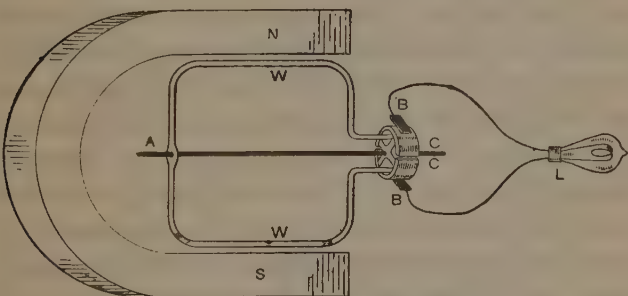
This explains the need for the commutator if we desire a flow of current in one direction only.

It has been said that the armature wires terminate in copper bars that are in contact with the collecting brushes. Now we know that there are in every revolution of the armature moments when each loop of wire in its turn does not cut



Dynamo producing Alternating Current

N and S, North and South poles of magnet. W, W, Coil of wire. A, Spindle on which coil revolves. R, R, Rings. B, B, Carbon brushes. L, Electric glow lamp.



Dynamo producing Direct or Continuous Current

N and S, North and South poles of magnet. W, W, Coil of wire. A, Spindle on which coil revolves. C, C, Commutator (split ring). B, B, Carbon brushes. L, Electric glow lamp.

the lines of magnetic force. For an instant each loop lies *along* the lines of force and therefore generates no current. Perhaps you can see that the moment when that is occurring is the time to seize for changing the current from one collecting bar or segment to the next brush. The revolving bars or segments to which the armature windings are attached are of such width and number that just at the critical instant, when the current direction in each one is changing, it comes into connexion with the opposite brush. You may think of the commutator, in fact, as a sort of rotating switch, timed to reverse the alternations in current exactly in step with the connexions of the brushes to the terminals.

So much for the dynamo, the machine by which mechanical power can be turned into electrical power. The same kind of machine can change the electrical power back again into the mechanical power needed for turning wheels and doing work of various kinds. To put it as shortly as possible, an electro-motor is a dynamo working backwards. It is not difficult to realize why this is so if we remember that a coil of wire carrying a current of electricity exhibits magnetic properties, and that by passing a current through the dynamo armature we convert it into a very powerful electro-magnet. The poles

developed, however, are intermediate between the field poles—at right angles to them—with the consequence that the unlike armature pole is continually attracted to the unlike field pole, and vice versa. There is thus a constant "torque" or twist exerted on the armature, the poles, of course, remaining the same, because they depend on the direction of the current, which never changes, however fast the armature may be rotating.

It is rather an interesting point in the story of electrical engineering that the electro-motor really came in advance of the dynamo. Inventors were eager to develop a machine for converting electricity into mechanical power before there was any electricity worth speaking about. We have seen how Faraday paved the way; and in a very short while a host of experimenters were seeking to perfect appliances for making their trivial electric currents do mechanical work in a small way. One of the most successful of these was invented by a man named Jacobi as long ago as 1838. Jacobi arranged two groups of electro-magnets, one group on a disc revolving within the field of a stationary group. A battery supplied the current, of course, and it is said that he succeeded in propelling a small boat. Queer to think, is it

not, that one of the very latest developments of electricity—its application to ship propulsion—was also one of the very earliest? Of course, there have been small accumulator-driven electric launches for many years; but, as I mentioned in connexion with the steam-turbine (p. 51), it is only in the last year or two that electricity has come to be looked upon as a practicable means of driving great ocean-going liners. The reason really lies in the wonderful efficiency of modern electrical machinery. We can turn mechanical into electrical power and back again to mechanical without losing more than eight or ten units of energy in every hundred. This is due to the researches and inventions of a host of scientists and engineers of all nationalities, but the name of Gramme, a German who worked wonders with the dynamo half a century ago, is probably the most prominent in the minds of engineers.

In the minds of most persons, perhaps, it is as a source of light that electricity in harness most decisively demonstrates its usefulness. It is as lighting power and heating power (which is the same thing) that electricity comes into most houses. We do not stop to think that light in the hours of darkness is a first essential for civilized man, nor that the world of living

men must have been a truly terrible place after sundown less than a hundred years ago. Lots of us—grown-up men and women as well as children—are still afraid of the dark, not, as some suppose, because we are unused to it; the reason is far deeper and more mysterious than that; the fear being probably an inheritance from ancestors down the ages when there was no light when the sun had gone, and no wit in man to create it for himself. And a hundred years ago, or not much more, there was no means of artificial light that was better than that possessed by advanced races two thousand years earlier. Aimé Argand, the French chemist who first produced an oil-lamp that was any better than a candle, was not born until 1755. William Murdoch, the restless Scotsman who was so picturesque a figure in the story of steam-power, lighted Boulton and Watt's works at Birmingham with coal-gas in 1802; but artificial light as we know it is a product of our own time.

Light was really one of the first manifestations of the newly discovered electric force. The distinguished savant who gave Michael Faraday his chance—Sir Humphry Davy—invented an electric arc-lamp in 1810. Electric light, like light from most other sources, is

produced by raising the temperature of something that is highly resistant to heat to a degree at which the radiations have a wave-length short enough to be absorbed by the eye. When you hold a poker in a hot fire, it begins to radiate waves of energy—heat waves, which your skin may be able to detect, but not your eyes, which are insensitive to all but the short rays. The less the heat, that is, the lower the energy radiated, the longer the waves. As the poker gets hotter, the energy is radiated faster and faster and the waves get shorter and shorter, until at last the eye can see them as a dull red glow. In a little while longer, the short heat waves are emitted more rapidly still, and we say the poker is white-hot; it is then radiating the waves, from the long ones at the red end of the spectrum to the very short ones at the violet end, that our eyes recognize as light.

Sir Humphry Davy found that one way of producing intense heat in a substance was to pass an electric current through it. You see how the electromotive force required to make the current pass through the substance is energy that is taking the form of heat. He also found that if two rods of carbon in a sufficiently powerful electric current are brought together and then drawn a little way apart, the current

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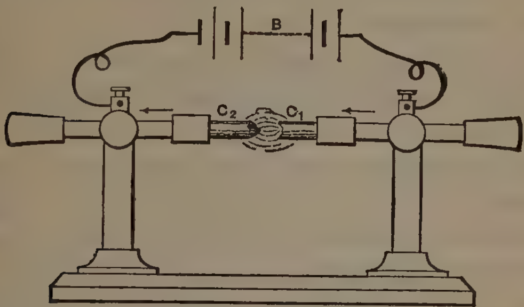
By courtesy of *The Daily Chronicle*

DRIVERLESS TRAINS OF THE G.P.O.

They take letters from Paddington to Whitechapel along a 6½ mile tube railway

continues to flow across the gap. This gap is the electric arc. The points of the carbon rods, owing to their resistance to the current, become intensely hot, and the space between them is filled with particles of incandescent carbon. The result is a dazzling white light—a noisy, hissing, spitting light too, exceedingly unpleasant at close quarters.



Davy's Apparatus producing an Arc

B represents a voltaic battery, C_1 and C_2 the positive and negative carbons.

More than fifty years passed before any serious use was made of Davy's invention. There was no electricity to speak of, neither was there any advertising of the kind that we know, to thrust things under our noses so that we are obliged to think about them. But by degrees electric arc-lighting found its way into city streets and big buildings like railway

stations. Still, there was no soft electric radiance in people's houses. Arc-lamps, vastly improved though they came to be, were quite unsuitable for that.

The invention of the incandescent electric lamp is an oft-repeated instance of two independent workers simultaneously arriving at the same result, unknown to each other. Thomas Alva Edison was one of the inventors and J. W. Swan the other. Both saw the need for a form of electric lamp, small, self-contained, silent, and safe, that could be scattered about tens of thousands of houses, shops, and offices, with a big generating station supplying the current to them all. In 1879 each produced a lamp in which a thread of highly refractive material was heated to incandescence in a glass globe from which the air was exhausted. Platinum was the material chosen by Edison, carbon was the choice of Swan; and as carbon proved to be the better material, the two inventors joined forces. Great difficulty was at first experienced in obtaining a perfectly even thread of carbonized cotton, which was the material used for the filaments. In Swan's early commercial lamps, the thread was produced by drawing it through fine holes, but he was soon able to improve on that, and his method is a very

interesting link between two industries without apparent connexion. Swan dissolved the cotton for his filaments and squirted the cellulose solution through pinholes, thus (in 1885) pointing the way to processes that have led to the great trade in artificial silk.

A comparatively small current at a high pressure is sufficient to heat the filament to incandescence—a temperature of about 3000 degrees Fahrenheit is needed—and invention has followed invention for making light at less cost. The carbon filament lamp is no longer able to hold its own against lamps in which the filaments are made of some of the rare metals. First came osmium, a rare metal found in the ores of platinum, introduced in electric lamps in 1904 by Dr. Welsbach. That was superseded in a few years by a tantalum filament lamp invented by an experimenter named Bolton. A few years more, and Bolton had discovered a better material in tungsten, the rare metal used for making very hard kinds of steel. Tungsten is so very hard that it cannot be cut. Bolton first tried to soften it by heating in an electric furnace, and did in fact make tungsten soft enough to draw into fine wires, but the filaments of drawn tungsten were so brittle that, although the lamps were

more than thrice as efficient as those with carbon filaments, they were of little practical use. A way, however, was soon found of dealing with the intractable material. The tungsten is ground to a fine powder and mixed with a suitable medium into a soft paste which is forced through minute holes. The threads so produced are subjected to intense heat, which removes the binding and leaves a resilient hair of pure tungsten.

A very important development in electric lighting occurred in 1902, in which year an Englishman named Cooper-Hewitt introduced a mercury-vapour lamp. This lamp is a long vacuum tube, at one end of which is a small quantity of mercury. The mercury gives off a vapour which possesses wonderful luminosity. In its improved form, the Cooper-Hewitt lamp most nearly imitates sunlight. The rays emitted extend far beyond the luminous wave-lengths at the violet end of the spectrum, and on that account are much used for medical purposes. Another lamp of a somewhat similar nature is filled with neon. Neon is an element existing only in very small quantities in the atmosphere, and its recovery as an article of commerce is one of the wonders of modern electrical magic. Until recently it could only be obtained in the

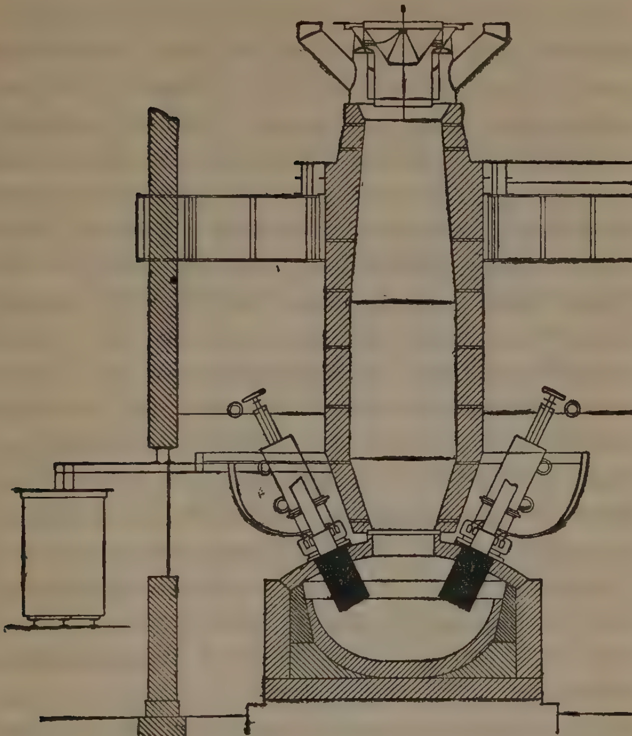
process of liquefying air, but the electrical decomposition of air—of which we shall have something to say a little farther on—has sufficiently cheapened the production of neon to enable the lamp in which it is used to become an article of general use. The neon light is very soft and beautiful. It has wonderful powers of penetrating mist and fog, and on this account it is used for aerial lighthouses like that at Croydon Aerodrome.

It is clear that electricity can give us heat without light just in the same way that it can give light without too much waste of energy in the creation of the inevitable heat. All we need to do to get heat is to interpose in an electric circuit some substance that by its resistance to the flow of current changes the electromotive force into heat force. Practically, the difficulties have been in the discovery of the most suitable resistant materials and the supply of electricity at a sufficiently low cost to convince people how terribly wasteful and extravagant are the old methods of making heat.

There is one kind of electric heat that, very fortunately, does not find its way into people's houses. The electric arc supplies the most intensely fierce furnace man has invented, and there are very few substances indeed that are

so intractable that they will not succumb to its terrific temperatures. The very useful metal aluminium—of which the common domestic uses, in the way of pots and pans, are by no means the only ones—owes its cheapness and popularity to the electric furnace. Bauxite—the ore containing alumina—cannot be smelted in coke- or gas-fired furnaces, and aluminium works are therefore placed where there is cheap water-power for making electricity. A still newer use for the electric arc is to burn the nitrogen in the air in order to form nitric acid. You know that nitrogen is a vital element of plant life, and that having taken it out of the soil for one crop, farmers and gardeners must replace it somehow before they can grow another. That has always been a difficult and expensive thing to do; and cheap fertilizers containing nitrogen electrically recovered from the air are a boon in which we all share.

The electric arc used in big furnaces is of course quite different from that in the arc-lamp, though it is the same in principle. Some are great flat discs of flame 6 feet across; others are long and narrow and may be 50 feet from pole to pole. These giants have little brothers, handy little fellows mounted on low trucks so that they can be hauled from place to place



Electric Iron-ore Reduction Furnace at Trollhättan

Four electrodes; two-phase current at 50–90 volts; consumption 2300 kilowatt-hours per ton of pig-iron produced from magnetite ore averaging 60 per cent iron.

When connected with the electric mains, they are ready to take on any little job needing the application of a few thousand degrees of heat

They can be seen at work in the streets, welding cast-iron and steel gas and water mains so that they may be perfectly continuous impervious pipes from end to end. Electric welding is a common process in engineering shops and foundries. The workmen wear special screens to keep the intense dazzle of the arc out of their eyes, and the outpourings of ultra-violet rays from injuring their skin. But not all electric furnaces employ the arc. There are types specially suitable for smelting iron and other ferrous metals in which the heat is generated by the metal's own resistance to the current. Such are called induction furnaces, and in one respect—the possibility of entirely excluding air—they are the most satisfactory yet devised.

Another very important and—to those who live in densely populated districts—very conspicuous use of electricity is in driving trains and trams. You may know that the early horse-drawn tramways resulted from the efforts of an American named (quite inappropriately) Train. But long before the time of Mr. Train, in the very early days of railway construction, in fact, when the steam-locomotive was not completely secure in the favour of those who promoted railways, a Scottish engineer made the first electric car. He was Robert Davidson, of Aberdeen.

The vehicle he made ran on the newly opened Edinburgh and Glasgow railway in 1837, and because it was noiseless and smokeless, entirely self-contained and devoid of visible means of propulsion, it created a very great sensation. But it had nothing to boast of in the way of speed—four or five miles an hour, perhaps; and since its primitive motor (grandiloquently called an " electro-magnetic engine ") took current from a galvanic battery, the first electric car was unlikely to earn dividends; as I have said before, zinc is a very expensive fuel. Yet that brave experiment of Davidson's was an astonishingly faithful forecast of what might be done in using electricity as motive power in a time when there was cheaper electricity to use. Davidson's electric rail motor-car in 1837 and Jacobi's electric boat in 1838 were both prophetic.

The first practical electric railway was laid down by Ernst Werner Siemens at the Berlin Exhibition of 1879. The names of Werner Siemens and his brother Karl Wilhelm constantly recur in electrical history. It was a little " toy " line a few hundred yards long, and there were only three carriages for passengers, who travelled at the thrilling speed of six or seven miles an hour. But, as far as it went, the

railway was entirely successful. Much about the same time Thomas Alva Edison laid down an experimental track running through the grounds of his laboratory at Menlo Park, New Jersey. On this line, which was purposely planned with most alarming curves and gradients, Edison demonstrated the capabilities of a twelve horse-power electric locomotive. Two years later—in 1881—the first electric tramway in the world was opened in Lichterfelde, a suburb of Berlin.

In one respect, the electric locomotive quickly showed itself superior to its steam rivals. It is smokeless, and therefore the ideal form of power for working trains through very long railway tunnels. The ventilation of mountain tunnels is always difficult, since it is too expensive to drive air-shafts through many thousands of feet of earth overhead. In the older tunnels through the Swiss Alps—the Mt. Cenis, six and a half miles long, and the St. Gothard, nine and a quarter miles long—there was always the danger of the drivers of the locomotives becoming insensible through the poisonous fumes that filled the tunnels. So as soon as electrical engineering had sufficiently advanced, the steam-locomotives were dispensed with. The trains going through the tunnels from France

and Germany to Switzerland and Italy are long and heavy, and the gradients steep, so that very powerful locomotives have to be used. The need gave a great impetus to the search for the best types of motors and current collectors.

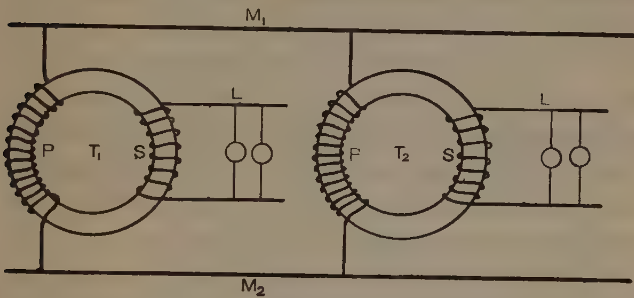
There are many ways in which electric traction excels steam-power on railways. Electric trains, whether they are hauled by great locomotives with several giant motors, or composed of coaches on the multiple-unit system, in which the power units are spread throughout the train—can get up speed and come to rest much more quickly than steam-trains. It is therefore possible to increase the carrying capacity of a line practically to the extent of doubling it. Then, again, electric locomotives can be made much more powerful than steam-locomotives, weight for weight. They do not have to carry the apparatus for converting the heat of the fuel into tractive effort—that is done at the generating station; and the torque, or turning effort, of an electric motor is about twice that acting on the driving wheels of a steam-locomotive. On one American railway, the Norfolk and Western Railroad in Virginia, a single electric locomotive of 4000 horse-power and weighing 245 tons now hauls coal trains up to 3000 tons in weight over a line that used to

require the power of three gigantic locomotives, weighing together about 700 tons, to work the same trains.

You may remember that I pointed out in the last chapter that effective electrical energy depends on quantity and pressure. Naturally, the pressure or electromotive force required for driving very powerful motors must needs be high. The current may be continuous, with a pressure of from 500 to 3000 volts, or alternating, with a pressure up to 60,000 volts or more. It is always easier and cheaper to send electricity to a distance at a high pressure. You can see, perhaps, how a thin but, as it were, a very intense stream of current requires a smaller conductor than a much broader and more sluggish current would need. Generally, electricity is generated at very high pressures, but it may be more convenient to make it at a low potential. But in that case it will be necessary greatly to increase the electromotive force if we wish to send the current over a distance of hundreds of miles. Then, again, we encounter another difficulty. Currents of great intensity are highly dangerous to life and are useless for driving machinery. We cannot switch on electricity at a pressure of 50,000 volts to light a lamp or turn a motor. Fortunately, electricians have a mar-

vellously simple apparatus by means of which they can alter at will a comparatively thin stream of electricity at very high pressure into a broad stream at a much lower pressure, or a broad, sluggish stream into a thinner and swifter one.

The apparatus which effects these changes



Transformers

M_1, M_2, Mains in which a high alternating pressure is maintained. P, Primary coils arranged in parallel. S, Secondary coils. T_1, T_2, Transformers for reducing the pressure to suit the lamps L.

is called a transformer. There are many forms of it, but all function on the principle of the induction coil, which is based on Faraday's discovery that when a current is passed through one of two insulated wires laid side by side, a momentary current is induced in the other wire, but in the reverse direction; and that when the original or primary current is cut off, a momentary current is set up in the second

wire in the same direction as the primary current. Remembering that a wire carrying an electric current is surrounded by lines of magnetic force, we can see how it is that as soon as these lines of force cut across another wire, they set up a current in that wire. To transform continuous current there must, of course, be some means of making and breaking it—of flashing it on and off—but this reversal of direction occurs naturally in alternating current. As parallel wires of a very great length are needed to induce a powerful current, they are wound round and round an iron core, the primary wire being wound first and the secondary wire on top of it.

Obviously, the more turns there are in the coils, the greater the number of places where the lines of magnetic force issuing from each turn in the primary wire cut across the secondary wire. The more turns there are, therefore, the greater will be the electromotive force in the secondary coil. The current issuing from the secondary will be of higher voltage than that sent into the primary, and the result is, in effect, a "step-up" transformer. To reverse the process, that is, to reduce the high potential that is economical to transmit to the much lower potential at which electricity is used, a "step-down" transformer

is needed. In that case, the coils of wire are wound on the ring so that the primary circuit from the mains has many more turns than the secondary circuit, the effect being that the current induced in the secondary is greater in amount but less in pressure. By varying the numbers of turns in the two coils, it is possible to reduce or increase electrical potential to any relative pressures required.

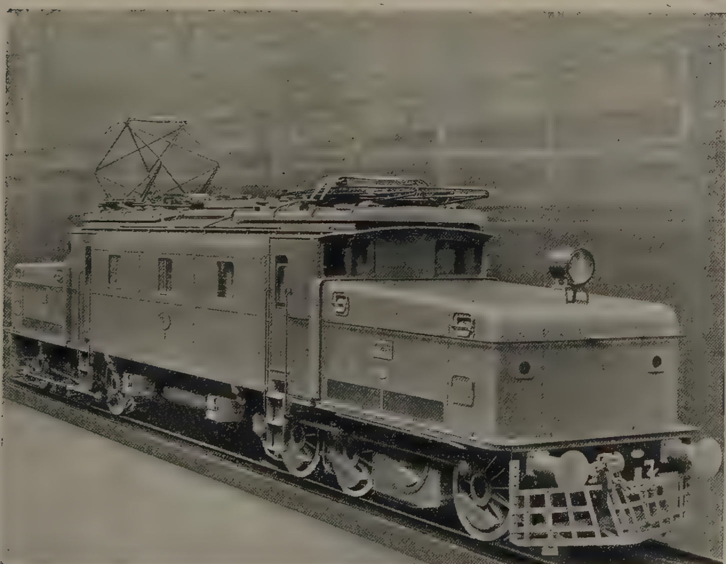
Like all other electrical apparatus, transformers are really very complicated contrivances, however simple they may be in principle. The nicety and perfection of manufacture—the exactitude that rejects dimensional errors of a thousandth of an inch—that is the standard of modern mechanical engineering is nowhere so well exemplified as in electrical machinery. Whatever the function we would have it perform—delicate and infinitesimal as Lord Kelvin's mirror-galvanometer, or monstrous as a 200-ton electric locomotive—what romance lies in the unending stream of raw material—base metals and precious, rubber from the tropics, neon from the air; and what consummate attainment in their fashioning! Consider the industries, crafts, and processes combining to fill so commonplace a need as an electric lamp, or the marvels of the works where the millions

of miles of electric wire are produced. Some wires are single strands as fine as the finest hair, some are covered with cotton, some with silk, some with gutta-percha. They may be twisted into cables of many strands, each insulated from the other; they may be coiled into a tiny space in the ampere meter on the dash-board of your car or in a dozen recesses of your wireless set; they lie along the ocean-floors, hidden wonders of a hidden world; and, as " live " wires, they span many a countryside, sagging between steel towers, each with its grim warning—SUDDEN DEATH!

I wish that it were possible to introduce to you the beauties and niceties of some of the common electrical appliances in everyday use. There is the meter, for instance, under the stairs or in the back kitchen, that relentlessly records the amount of current consumed by each household. What mysteries does its black exterior hide? The electricity passing into it may measure by electrolytic action, explained in the last chapter, or it may heat a tiny resistance to create a current of warm air that spins a little fan and so provides motive power for the gears that register the units consumed. Or again, it may be an electro-magnetic device as complicated as a watch and as beautifully made. And

THE FIRST ELECTRIC TRAIN

At the Berlin Exhibition of 1879



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By courtesy of Messrs. The Metropolitan-Vickers Electrical Co., Ltd.

MODERN ELECTRIC LOCOMOTIVE

2600 H.P. Great Indian Peninsula Railway Freight Locomotive. Length over buffers 66 ft.

what of the "dead man's button", the controller or master-switch that starts and stops every tramcar and electric train? This device is not itself a switch, but a powerful electro-magnet controlling the switches for the motors, and maintaining or breaking without risk or effort to the operator any or all of a dozen or more separate circuits. The "dead man's button" is a truly wonderful contrivance. It commands the pressure at which the current flows to the motors, which is highest at starting, stepping it down as required. It automatically reverses the direction of the current in the motor field-windings if the tram or train needs to go backwards. In the case of a train on the multiple-unit system, where there are motors on several coaches, it controls, through a maze of contacts, the circuits of all the motor fields, armatures, and resistances; and it is often used in combination with a separate transformer in which the current is stepped-down in many separate stages. For example, the current picked up by the train may be at 10,000 volts. The current required to energize the electro-magnets of the master-controller is 50 volts, that for the lamps in the train 100 volts, that for the motor compressing air to work the brakes 150 volts, while for starting,

accelerating, and speed-regulating the train motors all pressures from 300 volts down to 180 volts may be required.

Transformers play a tremendously important part in modern power-schemes. It used to be thought desirable to split up electricity supply into units specially adapted for particular requirements. One power-station in a city, for example, would generate direct current for lighting and power at comparatively low pressure. The street arc-lamps would be tapped directly off the mains, while there would be transformer-stations where the pressure was reduced for house lighting. Another power-station would send out alternating current at higher pressure for working the electric trams, while a third might exist solely for supplying very high-potential current to an electric railway. Such a system is bad and wasteful, and the modern aim is to generate in bulk all the electricity required over a large area, transforming it up or down in a hundred different places, if need be, so as to make it available for all the needs of the community at the lowest possible cost. The cheaper the current, the happier and healthier will the people be who can make use of it, not for transport and lighting and heating only, but for ten thousand tasks that at present

are tiresome or costly to perform. Electricity must wash up the plates and dishes, clean our homes and our clothes, sterilize our food and drink, mend us in sickness and maintain us in health. It shall grow and grind our corn, milk our cows, make our butter. It shall serve us in little things as in big things, a servant to fetch and carry, and a power to fulfil the most ambitious yearnings of humanity.

The era of electricity is not a consummation. Perhaps we are standing in the dawn.

CHAPTER VI

The Age of the Heat-engine

This is a very misleading chapter heading, because for three-quarters of a century, more or less, there was only one kind of heat-engine of practical value. And that, as I need scarcely remind you, was the steam-engine. This chapter has nothing to do with steam-engines, but is an attempt to survey the steam-engine's rivals and successors as prime movers, the different types of internal heat-engines, or, as they are more often called, internal-combustion or "explosion" engines.

I need not point out that every heat-engine, whether steam or internal-combustion, performs its work by the expansion and contraction of a gas that is alternately heated and cooled. Thus the fuel creating the gas is made to repay in a mechanical form some of the energy given to it as heat. The extent to which that repayment is possible, it is the business of the science of

thermodynamics to ascertain; and it is to progress in the study of that science that the development of the internal-combustion engine is mainly due. The theory of thermodynamics came to be studied as a serious science when first it was realized how terribly wasteful was the steam-engine of the heat stored in the coal. I think I gave a hint of this wastefulness of heat-energy when we were looking at the steam-engine. It amounts—in large compound reciprocating engines—to a loss of some 85 per cent of the total heat-energy supplied to the steam; you see, more than eight-tenths of the potential power is thrown away. Our forefathers wasted much more than those eight-tenths, and, from living in a country where coal was literally " dirt-cheap ", they did not much worry.

It was natural, perhaps, that a more economical form of heat-engine should arise in a land where the fuel problem was more acutely felt. Yet it was an Englishman who set people thinking that there might be a serviceable way of converting heat into mechanical power by exploding a mixture of gas and air in an engine. It was Sir George Cayley who, half a century before the time of the great mathematician of the same name, made himself something of a laughing-stock by putting forward such a preposterous

notion. The foresight of Cayley was remarkable, because his hint of an internal-combustion engine was the conclusion of far-reaching experiments in the possibility of mechanical flight. "Oh yes," said Cayley, "certainly we can fly—as soon as we have a prime mover that will give for every pound of its weight the needful margin of power."

Perhaps, in giving precedence to Sir George Cayley, we are scarcely fair to the memory of Robert Street, who did actually invent a gas-engine at the time James Watt was developing the steam-engine. Street's engine was dated 1794; but, as it would not work, we need say no more about it. Yet, the sensational prophecy of Cayley and the abortive gas-engine of Street connect chronologically with one of the great figures of the French Revolution. You remember Carnot—"the organizer of victory"—one of the Committee of Public Safety. His son has better cause to be remembered. Lord Kelvin said that in his opinion there was nothing greater in the whole domain of science than the work of that son, Nicolas Léonard Sadi Carnot.

Sadi Carnot was the founder of the science of thermodynamics, the branch of physics that explains the relations of heat and work; and it is on the understanding of the fundamental

laws that he established that the steam-engine grew to be less wasteful, and came ultimately to be far surpassed in economy by the internal-combustion engine. Gas-engines, oil-engines, petrol-engines, Diesel engines—one must regard them all as Carnot's "children". The family likeness of these children is easily recognizable. The little engine working on town-gas to turn out a local newspaper, the oil-engine chopping chaff or pumping water, the great producer-gas plants driving factories and lighting cities, the motor-car, the aeroplane, the big ship whose propellers are turned by Diesel engines—all are the same in general principle. In some, the fuel that is to be exploded to provide the necessary heat is made in bulk and conveyed to the engine from outside; in others—the petrol-engine, for example—it is vaporized and made into an explosive mixture with air as required for each working stroke. Modern engineers cavil at that word "explosive", because, they say, the very rapid burning under pressure of combustible gas that takes place in the cylinders is an entirely different thing from a real explosion, in which the combination of the spare carbon atoms of the explosive substance with the eager oxygen atoms of the air takes place instan-

taneously. And although the combustion must of necessity be rapid, it must not be too rapid. To make the best use of the heat, the burning must be controlled and prolonged. But we go ahead too fast.

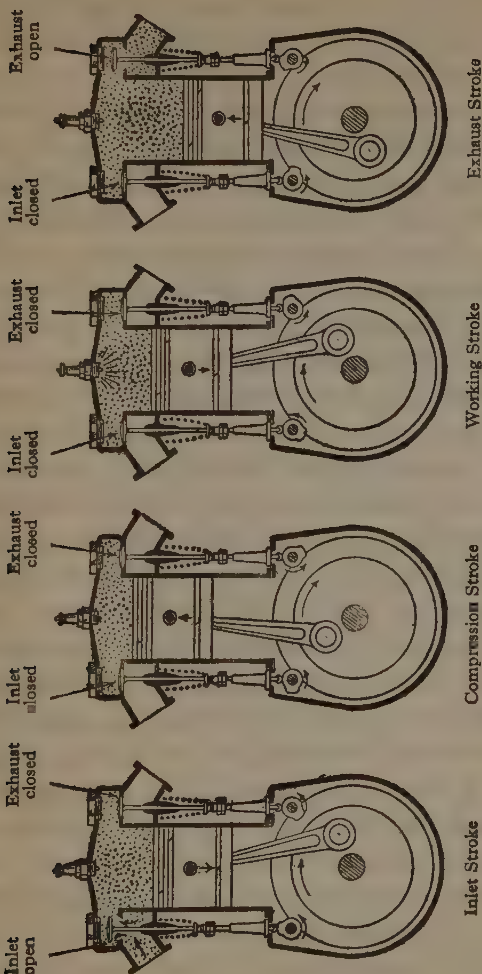
Otto's name invariably comes forward as the pioneer of the real application of gas as a prime mover. A great name, certainly, for most internal-combustion engines operate on Otto's "cycle"; but to call him the inventor of the gas-engine is unfair to Lenoir, whose gas-engine was put on the market in 1860. Lenoir's engine had a horizontal cylinder in which as the piston advanced it drew in an explosive mixture of gas and air. About mid-stroke this charge was fired by an electric spark, and the expansion of the hot gases carried the piston forward for the remainder of its stroke. During the back stroke, the spent gases were expelled, while on the other side of the piston a fresh supply of explosive mixture was drawn in and fired as before. As in modern engines, a heavy fly-wheel was used to store up the energy needed to provide the motion for the ineffective part of the stroke and to secure even running; and to dispose of the surplus heat that would otherwise render lubrication impossible by burning the oil, even if it did not crack or melt the working parts,

the cylinder was provided with an outer jacket, under which water circulated. To this extent, modern practice is based on the essentials of Lenoir's engine; the respect in which Otto's engine, which was introduced about 1876, showed a vast improvement was in the compression of the gas before it was fired.

Lenoir's engine was very wasteful; in economy it was on a level with the worst type of steam-engine. It took five or six times as much fuel per horse-power hour as the gas-engines of fifty years later. But a few years after its appearance Nicholas Otto, of Deutz, near Cologne, introduced a gas-engine that is very interesting, because it was a reversion to the atmospheric principle of Newcomen. The cylinder was vertical, and an ingenious system of gearing enabled the piston-rod to disengage from the engine-shaft during its upward movement. This upward stroke was the result of a veritable gas explosion. Bang! went the piston to the top of the cylinder, each time the gas was fired; and the piston-head being kept cool, the pressure of the burnt gases fell below that of the atmosphere, and down came the piston by the weight of the air. As it descended it automatically engaged with the engine-shaft and did its work. It is said that the contrivance was " excessively

noisy", and the statement does not put a great strain on our credulity; what is really remarkable is that the engine proved itself twice as efficient as Lenoir's in fuel consumption.

The engine that made Otto's name world-famous dates from 1876. It provides a very rare example of an invention that was immediately acclaimed and set to commercial use at a rate to make the inventor gasp and beg for breathing space. The new Otto gas-engines could not be turned out fast enough to meet the clamorous demand for them. In the ten years following 1876, Otto engines in tens of thousands honked and coughed wherever power was needed and there was gas to provide it; in big factories and little workshops all over the world—but thickest on the Continent—those cheap, thrifty, easily-managed heat-engines helped to cut down manufacturing costs. From the very start it was twice as efficient as Otto's earlier engine, and consequently four times as efficient as contemporary steam-engines. The secret of its success was in the compression of the charge of gas before it was exploded, and in the cycle of operations employed to secure the compression. Everyone who runs a motor-car and most of those who ride motor-cycles have a clear enough idea of the Otto or four-



Diagrams showing the Otto Cycle in a Four-stroke Engine

stroke "cycle". But in case—even after fifty years of its general application—some reader is still hazy, here is the explanation.

The first stroke of the piston (which, of course, is connected with the engine-shaft by the usual connecting-rod and crank) draws in, through a valve, the required mixture of inflammable gas and air. The inlet-valve is then closed and the piston commences its stroke back to the starting-point, compressing the charge of gas in the cylinder as it does so. At the beginning of the third stroke the compressed gas is fired—by an electric spark now, but in Otto's early engines by an "ignition tube" of burning gas outside the cylinder—and the gas, expanding as it burns with immense rapidity, forces the piston again down the cylinder. The inlet-valve still remains closed, during this, the third or power stroke, and also during the fourth stroke. But at the commencement of the fourth and last stroke of the cycle, a second valve opens to permit the passage out of the cylinder of the burnt gas. As this stroke is completed, the exhaust-valve closes and the inlet-valve opens again for the piston to suck in a fresh charge of gas.

No plan of operations more simple and effective has yet been devised. There are many different mechanisms for operating the valves;

there are two-stroke engines with ports instead of valves; but practically all internal-combustion engines, big and little, function on Otto's cycle. Only one of each four journeys of the piston up and down the cylinder is a power stroke; in other words, the crank-shaft receives but one power impetus in every two revolutions. For this reason, gas-engines have very heavy fly-wheels, and petrol-engines four or more cylinders with the pistons, valves, and ignition arranged so that the successive explosions provide a constant turning movement on the crank-shaft.

I have said that in a few years there were gas-engines honking and coughing all over the place. Minor troubles and disabilities these engines had in plenty, but the most serious thing against them as dangerous competitors of high-power steam-engines was the high cost of gas. It was an Englishman named Dowson who followed up the work of Otto, not with a new engine, but with a new gas. It is impossible to foresee the ultimate reactions of any fundamental invention on entirely disconnected industries. So, in order to understand what Mr. Dowson did, we must go back to Sir William Siemens' invention of the " regenerative " furnace, which cropped up, in its proper place, in the chapter on The Age

of Steel. Now, the gas-heated furnace, you remember, was applied to steel-making as a corollary of the increased demand for steel that arose from Bessemer's process. The Siemens furnace was invented for particular application to glass-making. And now we come upon it again as a way of escape for power-producers from the expensive gas produced by the distillation of coal in retorts.

Siemens gas-furnaces (with later modifications) form nowadays the chief source of heat in all industries in which much heat is needed. They provide the most satisfactory means known of combining as much as possible of the carbon in the fuel with the oxygen in the air, and so producing reasonably complete combustion. The method is to change the carbonic acid gas, which is a product of combustion and will not burn, into another gas called carbon monoxide, which will burn.

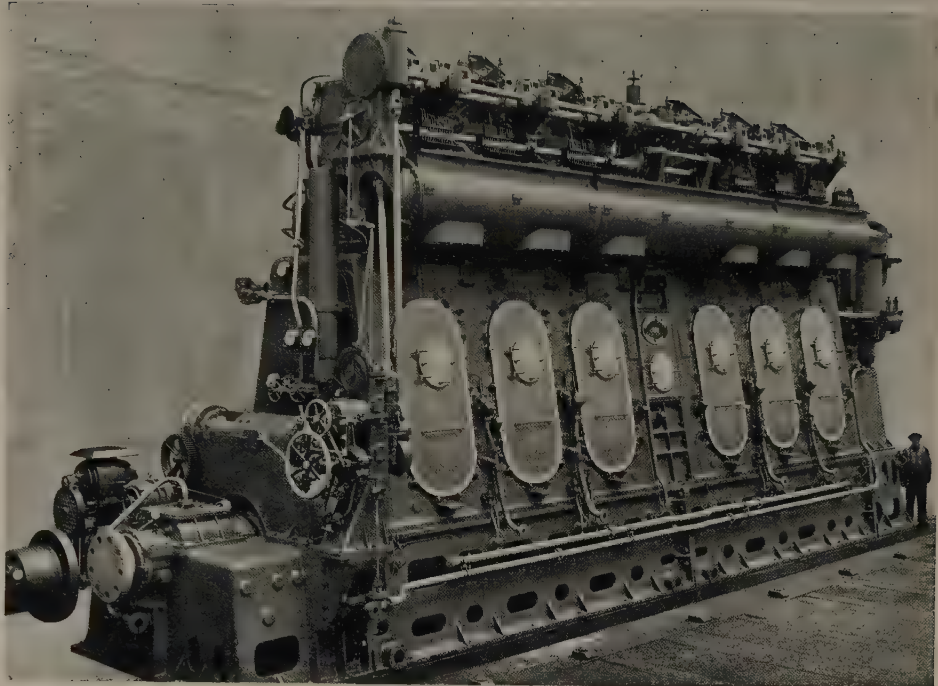
Let us see if a little elementary chemistry can help. The rusting of iron is a slow burning, the explosion of dynamite a very rapid burning, but otherwise both are the same as the burning of coal on a hearth. The chemical combination of the sugar and oxygen in your blood, to keep you warm, and the slow decomposition of the manure in the soil of the garden, are likewise

processes of burning. Two atoms of oxygen unite with an atom of carbon to form carbonic acid gas, and heat is the result. Bessemer gas is made in a peculiar kind of furnace, which is filled quite full of fuel and only permitted to take in a carefully regulated quantity of air. The result is that only the fuel immediately above the hearth really *burns*. There is a far greater mass of fuel on top of the burning part which is deprived of oxygen, but which, nevertheless, becomes incandescent. This mass of intensely hot carbon cannot combine with the oxygen of the air, because there is none; but there is passing up through it the carbonic acid from the burning fuel on the hearth, and this gas, having in each of its particles an atom of oxygen to spare, attracts another atom of carbon and becomes changed from the non-combustible carbonic acid to the highly-combustible carbon monoxide. CO_2 becomes $2CO$. Clearly, it has an additional carbon atom that will attract two more atoms of oxygen from the air.

This, then, is the Siemens gas that, conveyed in pipes like any other gas to the place where it is wanted, is the main source of furnace heat. What Mr. J. Emerson Dowson did in 1878 was to improve this gas, by making it much richer and more suitable for

gas-engines. By sending steam into the furnace along with the air, Dowson added to the carbon monoxide fresh supplies of oxygen and hydrogen. This is the famous producer-gas which really inaugurated the triumph of the gas-engine. Very large gas-engines came to be installed for all sorts of work that had hitherto been performed by steam-engines, for it was found that the former made double the use of the heat supplied to them. The impetus given to the design and manufacture of such engines, together with the growing need for making the best possible use of fuel, led, in Germany and Belgium particularly, to the development of types that could work efficiently on the waste gases from the blast-furnaces.

Mr. Dowson's work did not end with the perfection of the producer-gas plant just described. This plant was admirably adapted for work on a very large scale, or for supplying a number of engines from a single producer, but it scarcely filled the needs of the smaller user, who was apt to be alarmed by the cumbersome gas-holder necessary, and the somewhat bulky appliances for cleaning the gas and ridding it of tar. The solution did not come for a long time, although others besides Mr. Dowson were at work on the problem. But at the beginning of the present



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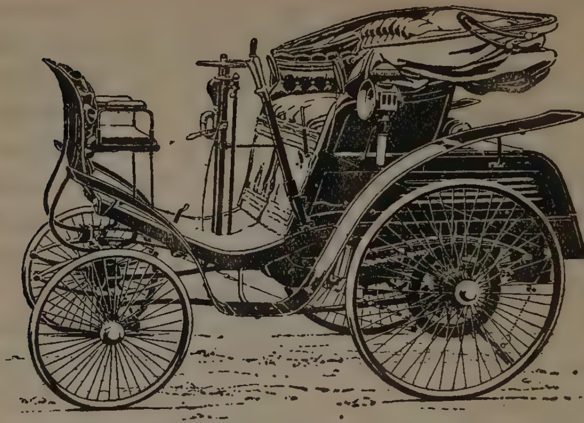
By courtesy of Messrs. The Wallsend Slipway and Engineering Co., Ltd.

A 3725 B.H.P. WALLSEND-SULZER DIESEL ENGINE

One of two installed in the Twin-screw Motor Cargo Ship *Zealandic*

century—twenty-five years after the introduction of his original producer-gas—Mr. Dowson had perfected the suction-gas plant that gave a new impetus to the gas-engine. In principle this is the same as producer-gas, the important difference being that the supply of air and steam to the furnace, and consequently the amount of gas generated by the plant, are directly controlled by the movements of the gas-engine. In other words, the engine makes its own gas as it requires it. The suction stroke of the piston draws into the furnace the proportions of air and steam needed to maintain the gas supply, the steam being the product of the waste heat in the water-jacket of the engine. The suction-gas plant ranks among the most important inventions of modern times.

Dr. Otto, "the father of the gas-engine", had a very able lieutenant in Gottlieb Daimler, the man who had the best right to be known as the "father of the motor-car", and one whose name is still appropriately perpetuated by one of the best-known makes of car. Daimler made the first motor-bicycle and rode it for several years. I have seen, somewhere, a photograph of John Boyd Dunlop, showing quite an elderly gentleman, riding the first pneumatic-tyred bicycle. As a matter of fact, Dunlop was forty-



Motor-car made by Messrs. Benz & Co. in 1888, and now preserved in the Science Museum, South Kensington, London

Probably the first petrol car brought to England. The car runs at about 10 and 5 miles an hour respectively on the two speeds and is still in working order.

eight when he took out his first patent. Daimler was fifty-two when he set out on his first motor-cycle ride. These two men, no longer in the first flush of youth, were, with Karl Benz, the true pioneers of the present era of swift road travel.

Daimler came a couple of years before Dunlop. Of the finest type of scientifically trained engineer, he had acquired experience in some of the best English engineering shops before he joined Otto. The task he set himself, to adapt the heavy and relatively slow gas-engine to the

propulsion of vehicles, was difficult enough. The engine had to be much smaller and more compact, much lighter, and three or four times as fast. The tube ignition had to be replaced by an internal electric spark occurring at the right moment, as in Lenoir's engine, and mechanism contrived for vaporizing a liquid fuel like benzene. An Austrian engineer, Siegfried Markus, had fixed a motor-engine to a hand-cart (of all things); an Englishman, Thomas Butler, had fashioned a motor-engine with carburettor and magneto, both in advance of Daimler. Karl Benz of Mannheim, who died in 1929 at the age of eighty-four, was the son of an engine-driver. He was the founder of the great motor firm bearing his name, and the inventor of one of the earliest motor-cars—a 2½ h.p. tri-car that, in 1883, accomplished a journey of 100 yards. But Daimler leads from the fact that his motor-cycle was a practical success; and the engine, improved in design, was sold to the French firm of Levassor in 1889. In 1891 a Daimler-Levassor motor-car ran from Paris to Brest, and from that trip one may date the ramifications of a vast industry.

There are those who think that the petrol-engine, though barely fifty years old, has effected a more complete revolution in men's

lives and habits than any other invention. It has had a far wider influence on travel than the steam-engine, for it has won us the power to fly. A huge oil industry, a huge rubber industry, a huge electrical industry—a barely credible improvement in high-speed production and methods of distribution have followed from the work of Otto, Daimler, and Dunlop,[1] and their virtual disciples. If you stop to think of it, the most wonderful thing about the motor-car is the immense pains that have been put into it to make it " fool-proof ". Here is a highly complex combination of machinery manufactured to run as regularly and efficiently as a good clock, not at the hands of expert users, but for every unskilled man or woman who cares to take the driver's seat! The average unmechanical car-owner cannot have the slightest conception of the toil and tribulation, brains and pains, in laboratory and workshop, and at the testing bench, that have gone to attain this astonishing perfection.

And now for the last phase of the gas-engine era. Experiments are now going forward to discover whether solid fuel, such as coal ground to

[1] Thomas Boyd Dunlop is entitled to full credit for the invention of the pneumatic tyre. It is true that another Scotsman, William Thomson, had made rubber tyres forty years earlier, but Dunlop was quite ignorant of Thomson's work.

a fine powder, can be satisfactorily used in an internal-combustion engine. Doubtless a practical application of this method will one day be realized, but we cannot stop to discuss this possibility. The problem it presents is at least no more difficult than that which Dr. Rudolph Diesel succeeded in solving in 1895. It might be supposed that by the end of the nineteenth century technical opinion would have been prepared to assimilate revolutionary ideas in the application of the laws of thermodynamics. But, in England especially, engineers clung so tenaciously to the steam-engine as the lord of prime movers that, in spite of the acknowledged superiority of the various forms of internal-combustion engines, steam-power maintained a lead that was scarcely challenged. In other words, even after nearly a hundred years of experiment and research had confirmed the soundness of Sadi Carnot's theories, power users were generally content to waste eight-tenths of the coal brought out of the pits.

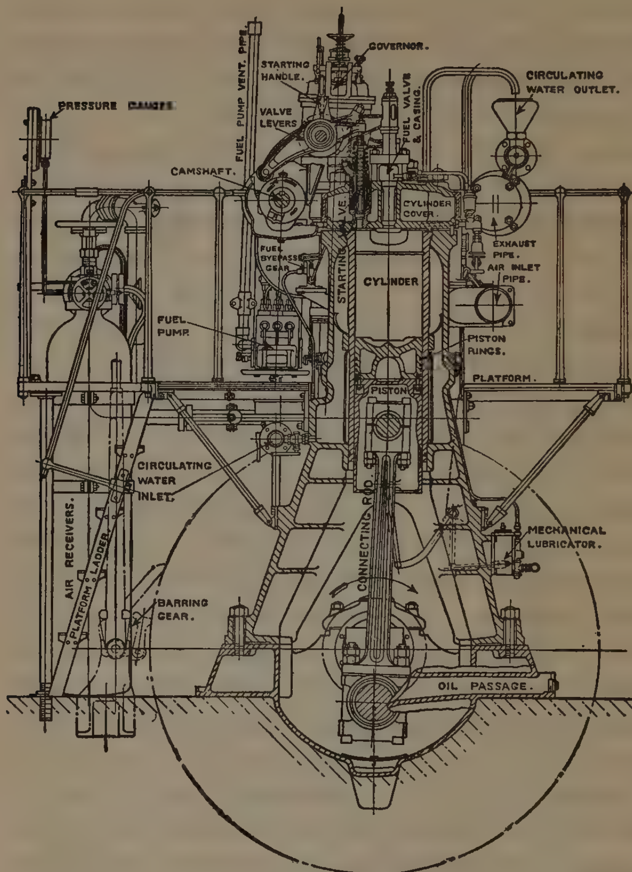
Lord Kelvin was one of a handful of men in Britain who saw in Dr. Diesel's pamphlet on "The Theory and Construction of a Rational Heat Motor" an idea of profound importance. This pamphlet was published in 1893, but it was not until 1897 that Lord

Kelvin was able to prevail on a Glasgow firm of engine builders to put Dr. Diesel's theory to actual test. I suppose we might find the spectacle of some backward South Sea tribe at work on its first home-made electric-lighting plant mildly amusing. That was rather how continental technicians regarded the successful trials of the first British-built Diesel engine in 1897.

Readers of the more serious newspapers and reviews tumble constantly on references to Diesel engines: a new liner is launched; a new fuel, such as waste vegetable oil, is experimented with; a motor-lorry makes a sensational trip on crude tar-oil costing fourpence a gallon; a French engineer applies it to an aeroplane, or the council of a great city to a new power undertaking; and although it has been a subject of technical discussion for thirty years, the general public has still an extraordinarily hazy notion of what a Diesel engine is. So let us begin by saying that the Diesel engine has attained an effective efficiency of the heat units in the fuel of some thirty-five per cent, compared with the average of fifteen per cent efficiency in the best steam-engines, and twenty-five per cent in the most economical types of suction-gas engines. That

is surely a very great attainment; but it does not necessarily follow that the Diesel engine, nor, for that matter, any other type of engine, is always the best in any circumstances. There are frequently conditions in which appears the paradox of the more efficient prime mover becoming the less desirable, from the intrusion of local factors which must control the choice.

Diesel engines have two very distinctive features among engines on the internal-combustion principle. The fuel used is crude residual oil, that is, the heavy, almost viscous fluid remaining from the partial distillation either of coal or petroleum. After the lighter and more marketable hydrocarbons have been distilled—paraffin and petrol from oil, benzol and naphtha from coal, together with the manifold products of fractional distillation, valuable chemicals, dyes—there remains this tarry substance which is the food of the Diesel engine. Not many years ago the problem was how to get rid of the ever-growing accumulations of this "waste". It is still not merely cheap, but, bulk for bulk, the cheapest fuel on the market. The other peculiarity of the Diesel engine is that the fuel is burnt in a liquid form, that is to say, it actually enters the cylinder as oil, not as a mixture of air and inflammable vapour as in the



Sectional End View of Mirrlees-Diesel Engine (Mirrlees, Bickerton & Day, Ltd.)

The engine is started by running it on compressed air. When sufficient speed is attained the starting lever is thrown into the running position.

gas-engine or the paraffin- and petrol-engines. There is no carburettor and no ignition device.

What happens is this. In the case of a Diesel engine working on the Otto—or four-stroke—cycle, the first or suction stroke draws into the cylinder nothing but pure air. On the second, the compression stroke, the piston drives the air back to a pocket at the head of the cylinder, where, all the valves being closed, it is under a pressure of about 500 lb. to the square inch. Your bicycle pump gets hot because a great deal of the energy you have put into it in compressing air is transformed into heat.[1] Well, then, the compressed air between the piston and the cylinder head, at a pressure of 500 lb. to the square inch, is not merely the equivalent of a very powerful spring; some of the energy required to compress it has gone to make it very hot. Its temperature is somewhere in the neighbourhood of 1000° F. This, then, is the moment chosen for injecting the fuel oil. No electric spark or other ignition device is needed, because the oil ignites spontaneously on contact with the intensely hot air. The expansion following the combustion sends the piston down again for the power stroke; the exhaust-

[1] The reverse of this, the absorption of heat from surrounding objects by an expanding gas, is the principle underlying the manufacture of artificial ice.

valve opens, and the burnt gas is scoured out of the cylinder by the fourth stroke.

The two-stroke cycle has been applied to Diesel engines with great success. In this type, each stroke is a working stroke, for the engine becomes double-acting. The cylinder is divided into two sections by exhaust-ports in the middle, and the valves for air and fuel are arranged both at top and bottom. The air is compressed and the oil injected first on one side of the piston and then on the other, the half of the cylinder in which combustion has taken place being exhausted of the waste products by the uncovering of the exhaust-port immediately before the next charge is fired at the opposite end of the cylinder.

It will be inferred, from the obvious impossibility of self-induction of the fuel charge, that a separate compressor must be used. There are, in fact, usually two compressors, one to work a pump which, by forcing air into the cylinder, secures the initial high compression, and the compressed-air engine for working the mechanism which literally squirts the liquid oil into the cylinder against the enormously high pressure of the air therein. And though the auxiliary machinery is consequently rather complicated, simplification at the hands of many designers has brought the Diesel engine to a

wonderful degree of adaptability and ease of control.

Though the modern Diesel engine is gradually forcing its way into fields that have hitherto been the particular province of steam or petrol, as on the railway and the road, it is for ship propulsion that its advantages have been, and are still, most conspicuous. Granted its superior economy in fuel consumption, the absence of bulky steam-raising plant, the smaller space required by the Diesel engine and the ease with which a liquid fuel can be loaded and carried in a ship are very obvious points in its favour. The ship-master is able to exchange boilers and coal-bunkers for additional cargo space and increased cleanliness; he is able to dispense with trimmers and stokers, and it is these considerations that have led to the very rapid increase of oil-engined tonnage since the bold Danish experiment of the *Selandia*—the first large ocean-going ship of this kind—a year or two before the Great War.

Take the case of a modern motor-ship like the Nelson liner *Highland Monarch*. Here is a ship of 14,000 tons, 520 feet long, specially designed for a particular class of trade, that of carrying frozen meat from South America. She is not a flyer (no motor-ship is that), but she

can make Buenos Aires from London in nineteen days, and with her wide decks and generous cabins there is not a steadier, roomier, or cleaner ship afloat. Two double-acting four-cycle eight-cylinder engines propel *Highland Monarch*, and the very elaborate refrigerating machinery is also driven by Diesel engines. There are plenty of other big motor-ships, and the number is continually being added to. But it must not be inferred that the steamship is necessarily moribund or obsolete. The owner must consider many factors in determining the type of propelling machinery best meeting particular needs, and sometimes steam comes out an easy winner, and sometimes the Diesel engine. There is no need to go here into the why and the wherefores of his choice.

The oil-engine, by reason of its high economy in fuel consumption and fuel costs, is likely to become a very formidable rival of the ubiquitous petrol-engine for road transport. It is running locomotives on Continental and American railways, saving about a quarter of the running cost of steam-locomotives of the same capacity.[1] The latest developments, and perhaps the most interesting, have been to adapt this

[1] Probably the first motor-train in the world, having an oil-engine generating electricity, and being driven by one man, was put into service on the Great Central Railway of England in 1912.

heaviest and most cumbersome form of internal-combustion engine for use in the air. In the chapter on The Age of Flight there is a short description of the great British State airship, of 5,000,000 cubic feet capacity, which will be the first craft of the kind to be oil-driven. The story of the evolution of her engines is of engrossing interest to all who can feel the lure of mechanical progress. The high inflammability of petrol adds, of course, a great risk of fire to an airship, and the use of a fuel like tar-oil, that does not give off an inflammable vapour until it is heated to about the boiling-point of water, offers quite obvious attractions. Add to that the saving in fuel of thirty per cent over existing petrol-engines, and it becomes clear that, if other things were equal, the builders would not for a moment hesitate in their choice. But against these advantages had to be counted the vastly greater weight, power for power, of the Diesel engine.

The heavy-oil injection engine weighed 100 lb. per horse-power, and the petrol aero-engine only about 2 lb. per horse-power. That was the point at which the engine designers of R101 started. Untiring research and experiment succeeded in cutting down that 100 lb. per horse-power, bit by bit, without any loss of

efficiency, until, in the engine known as the Beardmore Tornado, it had been reduced as low as 8 lb. per horse-power. Such are the engines, each of eight cylinders and developing 580 horse-power, that are built into the great airship. Before long, no doubt, so swift is to-day's progress in metallurgical knowledge and skill, it will be possible still further to reduce the weight, and high-speed Diesel engines will drone in the sky in serious rivalry with petrol.

CHAPTER VII

The Age of the Loom

It will be well that we should have in our minds a clear idea of what is meant by weaving. We could make a textile fabric by knotting yarns together, or by knitting, which, as you know, consists in making loops in a single continuous thread of yarn; but such fabrics are not woven. Weaving involves the regular intersection of a great number of threads running in transverse directions. The simplest form of weaving consists in tying a number of yarns of equal length to two cross-bars to hold them taut, and then working transverse yarns over and under each alternate fixed yarn until finally we have arranged a sequence of parallel yarns in two directions, continually crossing each other. The fixed threads are the warp; the set of crossing threads, inserted by lifting up every other thread of the warp, is called the weft.

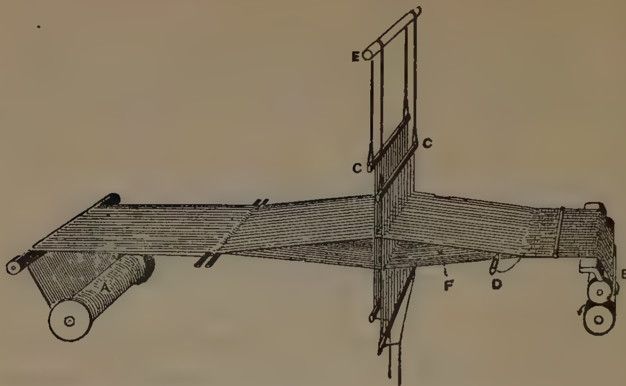
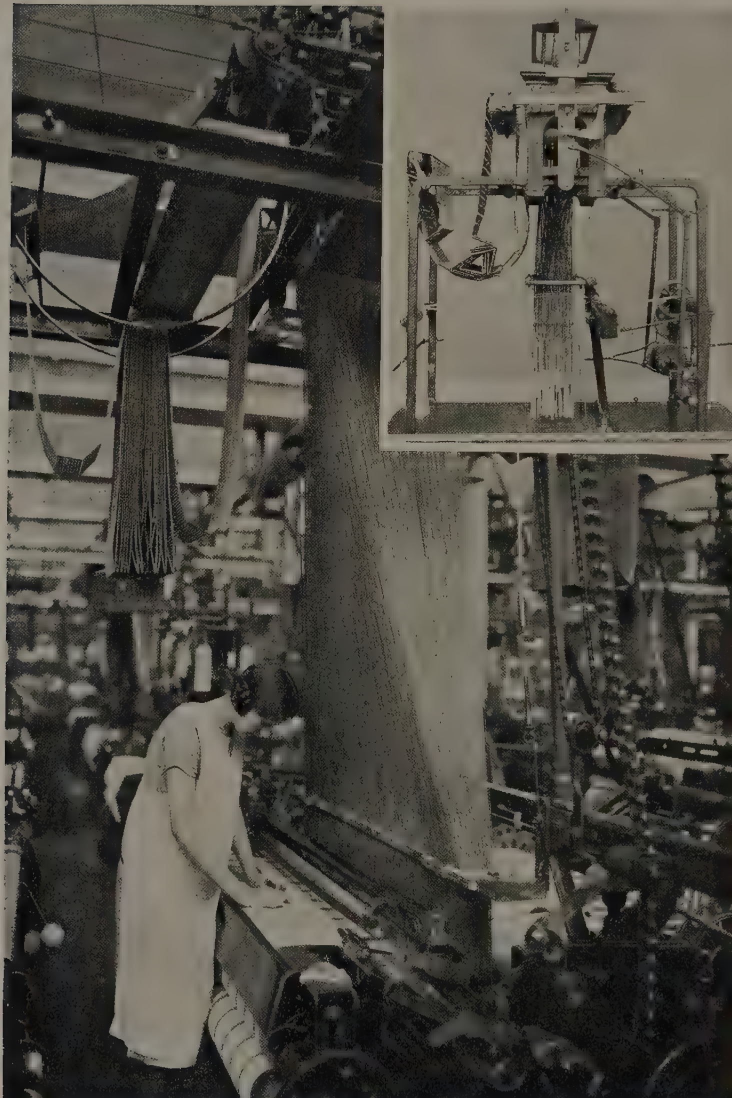


Diagram showing the Chief Parts of a Simple Hand Loom

A is the warp beam on which the threads are wound. B is the cloth roller on which the cloth is wound as it is made. C and C are healds connected by ropes passing over the log E, and when one is raised the other is lowered. D is the shuttle. F is the " shed " or gap through which the shuttle is thrown.

It does not require much wit to perceive that so simple a process can very easily be performed by mechanical means. The hand-loom, in which the alternate threads of the warp are raised and lowered to permit the passage of the shuttle carrying the weft thread, is almost as old as civilization. Anyone with a little skill in carpentry can fashion a workable hand-loom on which real cloth can be woven. First, there must be a rigid frame to hold the moving parts together, with a roller at each end, one for the attachment of the warp yarns, the other for the finished cloth to wind on.

By courtesy of the Royal Society of Arts



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By courtesy of Messrs. Horrockses, Crewdson & Co., Ltd.

THE JACQUARD LOOM

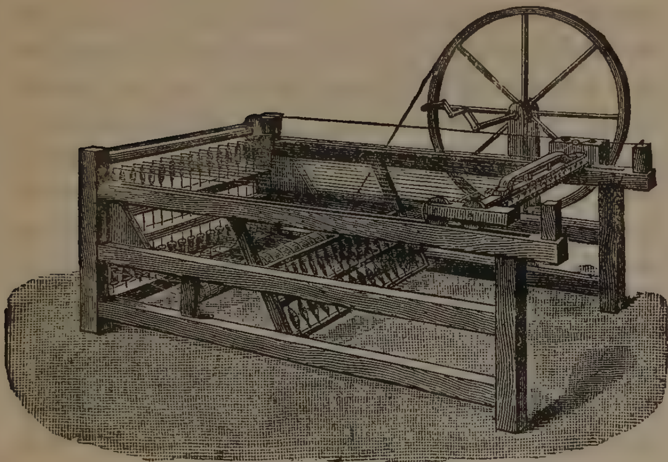
The small picture at the top is a model of a loom with a Jacquard apparatus attached, which is in the Science Museum, South Kensington, London. The larger picture shows the modern application of the Jacquard apparatus to fancy weaving

From the top bars of the frame two light bars are suspended, carrying vertical threads called *healds*, the healds being attached at their lower ends to two bars corresponding to the top ones, and so connected with a treadle that a movement of the latter raises one bar and depresses the other. Each heald has a loop, or small ring, through which a warp thread must be passed before it is attached to the cloth roller, the warp threads being equally divided between the two sets of healds. The first thread will be carried through the ring of the first heald of one set, the second thread through the first heald of the second set, the third thread through the second heald of the first set, and so on, until all the threads have passed alternately through the two sets of healds.

You can see that the effect of the treadle on the vertical heald threads, each with its hold on the warp threads, is to separate the latter into two sets—to open a gap in them—through which the shuttle, carrying on a bobbin the thread that is to form the weft, can easily be passed. As the foot of the weaver raises the rod carrying one set of healds, and depresses the rod carrying the other set, it forms the *shed* or gap between the separated warp threads through which he *throws* the shuttle, on the

end of a stick. The next movement of the foot raises the warp threads that were just depressed and lowers those that were raised; and he *throws* the shuttle again, this time in the reverse direction. With each upward and downward movement of the healds, a light batten swings forward with just sufficient force to press the weft threads firmly together.

So there you are; up and down go the healds, backwards and forwards goes the shuttle; and you can sit at your loom and weave, and reflect, if you please, on the strange fact that your slow and clumsy device is probably the source and fountainhead of mankind's sense of beauty and his desire for self-expression in art. From scratching pictures on baked clay and cavern walls, pictures of the vivid things around him—wild animals and armed men—he took naturally to the loom for expressing the truth of his greater leisure and security. The strength, the pomp, the splendour of the tribe or its leaders—how better could they be told than by fine feathers and fine fabrics? And so, hand in hand with civilization, weaving has gone down the centuries as the greatest of the crafts in which human inventiveness and ingenuity have exercised themselves. Twills and cashmeres, velvets and satins, gorgeous Eastern stuffs and



Hargreaves' Spinning Jenny

rough homespuns of English wool, alike were laboriously woven on simple hand-looms. The strange thing is that the application of power to this most elementary necessity of man—not steam-power, but the wind and water that were waiting for harness—was so long in coming.

It is James Hargreaves, an uneducated weaver and carpenter of Blackburn, that we must thank for one of the first-known developments of the spinning-wheel. Like thousands of his kind, Hargreaves used to take to the weavers the thread spun at home by his wife, and it happened on one occasion—so the story goes—that the

thread was not ready for him at the time he wanted to leave. Being no doubt impatient and anxious to be gone, with a careless movement he knocked over the spinning-wheel, which went on revolving on the floor, knotting and tangling the thread beyond all hope of usefulness. The sight of the wheel still going round and round gave Hargreaves the sudden idea that one wheel might be used to spin several threads at a time. Accordingly he set to work in secret, and after much thought and labour he produced a set of eight spindles twisting threads spun on one wheel. It was in 1776, or thereabouts, that this wonderful contrivance came into being.

An invention of almost equal importance was the "flying shuttle" of John Kay. Kay, who was born near Bury, in Lancashire, in 1704, seems to have been a most versatile and prolific man, but his treatment at the hands of the manufacturers who profited by his inventions was so shameful that comparatively little of his work ever reached the outside world. The flying shuttle only needed the use of one hand of the weaver, instead of two in the old fashion. This, of course, saved time and labour, and on that account the workpeople of the district rose up against it and, having destroyed Kay's home,

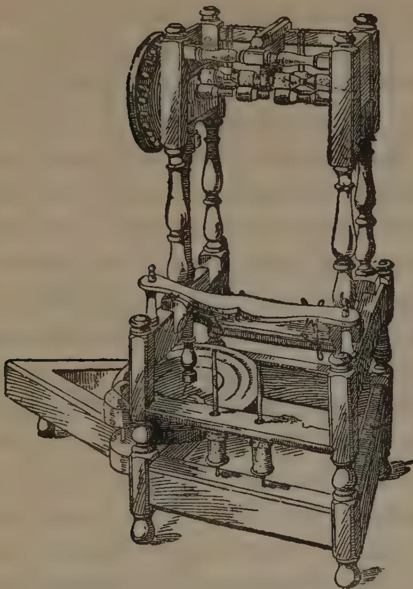
would have killed him too, but that he hid in a bale of wool and was carried away by his friends. Kay took refuge in France, where he died destitute and broken-hearted.

A great name to remember in the history of textile crafts is that of Richard Arkwright. Contrary to the fate of many other inventors whose lives were devoted to the furtherance of these crafts, Arkwright made a fortune by his abilities. Yet he started the poorest of the poor, being the thirteenth child of a humble couple of Preston. At first sight it would not appear that a travelling barber, such as Arkwright became, would have much opportunity of finding an outlet for invention, but his first success was connected with his own trade, for he thought out a new method of dyeing and preparing hair for wig-makers which brought him steady trade. His travels, moreover, took him continually in and out of the Lancashire cottage homes in which the men were occupied in weaving and the women in spinning. He was as familiar with these industries and their difficulties as he was with the problems of his own razors and scissors. He knew that although the material woven in Lancashire was called cotton it was always woven on a linen warp, as there was no means of spinning a cotton thread strong

enough for the purpose. The linen warps had to be imported from Ireland, and not only was the material dear but it was often delayed in transport, and the cottagers' work would be at a standstill while waiting for it.

Many times Arkwright must have called at cottages in his regular round, to be told that there was no money for hair-cutting that week as the weaving could not be finished; or the mothers would sell him their hair for wig-making because they had no other means of obtaining food for the children. Pity for his friends, and no doubt consideration for his own pocket, for the barber would always be a luxury to be dropped when trade was bad, set Arkwright thinking and thinking how to hasten and improve the spinning craft. At length his inspiration came, and in the most unlikely way it is possible to imagine, for who could foresee that any process used in an iron-foundry could be applied to cotton spinning? That, however, was what happened. Arkwright paid a visit to an iron-foundry, and while there he watched a bar of red-hot iron being drawn out between heavy rollers. The thought occurred to him: "Why should not cotton threads be drawn out between rollers?"

Fired with this new idea, Arkwright gave up



Original Spinning Machine made by Sir Richard Arkwright in 1769
Now in the Science Museum, South Kensington, London
The motive power was intended to be that of a horse.

all his other work, dropped his wig-making and hairdressing entirely, and devoted himself to thinking out the details of a machine which should revolutionize spinning. Needless to say, he had to work in secret for fear of the wrath of the very people he sought to benefit. Although reduced to utter poverty, he persevered until in 1775 he patented a machine which performed all

the stages in the manufacture of cotton yarn—carding, drawing, roving, and spinning. This was the machine that secured the prosperity of the cotton trade, for the rapid supply of yarn brought down the price of woven goods and stimulated the demand beyond the dreams of everyone but Arkwright himself.

The story of Arkwright has its parallel in the life of his great contemporary, Cartwright. Arkwright and Cartwright—those are the names that revolutionized the cotton industry, and brought to Lancashire wealth incredible to the minds of their generation; Arkwright, an untaught barber, pushing, facetious in his poverty (" Come to the subterraneous barber—he shaves for a halfpenny," ran the sign above his underground shop in Bolton), brought the spinning-frame that laid the foundation of the mass-production that was to follow from Cartwright's power-loom. Cartwright was even farther removed from sight and sound and influence of the craft than the other. He was a country parson, tutor to young noblemen. His chief delight and recreation were in the writing of very indifferent poetry. " This invention of Arkwright's is turning out so much yarn that there will never be men enough in Lancashire to weave it." So he heard a Manchester merchant grumble, and

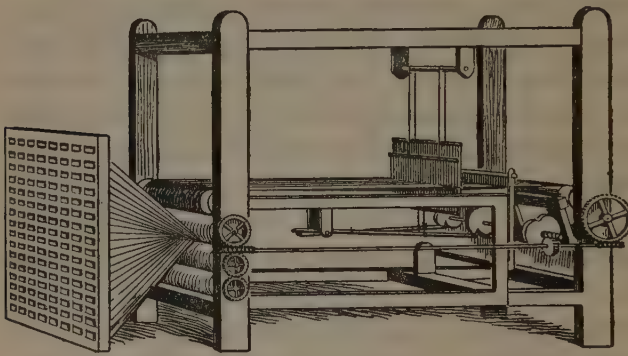
retorted: "Then you must weave it by machinery." "Machinery? Impossible!"

So the cultured cleric set to work. He tells that he had been vastly taken by the motions of a mechanical chess-player he had seen in London. Well, if a machine can be made to play chess, thought the Rev. Edmund Cartwright, a machine can be made to weave. He had no knowledge of weaving, mark you; in fact, not only had he never seen a loom, but he confesses complete ignorance of the principle on which it is worked. The astonishing man employed a carpenter and a smith to construct his mechanical loom. "To my great delight," he says, "a piece of cloth (such as it was) was the produce. As I had never before turned my thoughts to anything mechanical, either in theory or practice, nor had ever seen a loom at work, or knew anything of its construction, you will readily suppose that my first loom must have been a most rude piece of machinery. . . . The reed fell with a force of at least half a hundredweight, and the springs which threw the shuttle were strong enough to throw a Congreve rocket. In short, it required the strength of two powerful men to work the machine at a slow rate, and only for a short time."

Admirable Cartwright! What, in the age-long

story of invention, is more inspiring than your "most rude piece of machinery"? The sequel, in his own words again, runs thus:

"I then condescended to see how other people wove, and you will guess my astonishment when I compared their easy mode of operation with mine. Availing myself, however, of



Cartwright's Power-loom

what I then saw, I made a loom in its general principles nearly as they are now made, and it was not till the year 1787 that I completed my invention." That invention, I may add, was the parent of the marvellous modern power-looms, so incredibly complicated that they seem impossible to describe even in their first principles.

The Rev. Edmund Cartwright had by no means finished with the textile trade. There

were intervals of teaching, preaching, versifying; the erection of a factory at Doncaster for the production of his machines; and, of course, great expectations of material profits that were very, very slow in materializing. Then we find him at daggers-drawn with the woollen operatives — fifty thousand stalwart Yorkshiremen petitioning Parliament to forbid the use of his wool-combing invention.

Britain has always been justly famous for the excellence of its woollen goods. This was originally due to the fact that her northern sheep grew thick long fleeces to protect themselves from the cold, which the women spun into strong yarns for the weaver or knitter to make up. That is the wool industry in its simplest form. But towards the end of the eighteenth century two forces were at work to complicate the trials of the manufacturer. One was the strong influence of the French immigrants who settled in England to escape the horrors of the Revolution and brought with them notions of dress and fabrics hitherto unknown in England; the other, of course, was the persistent advance of machinery. Thus, while the cotton-spinners were undergoing agitation in Lancashire, on the eastern side of England the wool manufacturers were almost equally disturbed.

The first of the innovations was brought about by our friend the Rev. Edmund Cartwright, who found time to turn his attention to the tedious process of wool-combing. Before wool was ready for the spinner the fleeces had first to be sorted and the wool graded, not only according to the age and breed of the sheep, but also to the different parts of the body from which it was shorn. Then the fibres had all to be straightened and combed, which took a very long time, and when the demand for woollen goods began to increase with the general improvement in trade and prosperity, the wool-combers could not work fast enough. Cartwright's machine was worked by a horse turning a shaft, thus operating a revolving comb which could straighten out more "locks" of wool in a given time than several men. Although the manufacturers who adopted the machine had to face the consequences and submit to having their property wrecked, progress could only be slightly delayed by such tactics.

Wool lends itself much more readily to different kinds of treatment than either cotton or flax, and therefore a great many ingenious machines have been brought into use to produce different woollen fabrics. When we think of the cottager with her spinning-wheel, toiling often

far into the night to produce the few skeins of yarn required by the weaver on the morrow, and then visit a mill where a single machine turns out nearly four hundred *miles* of thread in one day, we realize something of the difference in production which a hundred years or so has brought about.

Arkwright—Cartwright—and then comes Jacquard. These three names stand out, as it were in letters of gold,[1] amongst the great host of textile inventors. We have noticed in two of them the strange improbability of their careers—the lack of mechanical knowledge and skill, ignorance where we had the right to presuppose intimacy. Similarly, if we were asked to guess who won a certain prize offered by the English Society of Arts in 1802 for a lace-making machine—a prize, by the way, which they had little hope of being able to award—we should say: " Someone who has an intimate knowledge of the manufacture of fine stuffs and also great experience in the design of mechanical contrivances." Yet this description could hardly be given of Joseph Marie Jacquard. True, he was the son of a silk-weaver of Lyons, but so poor was the weaver and so wretched the pros-

[1] I have not forgotten Samuel Crompton; but his spinning "mule" was really a combination of the inventions of Hargreaves and Arkwright.

pects of the silk-weaving trade that Joseph Marie at an early age declared he would have nothing to do with so beggarly a calling. He seems, indeed, to have shown no particular aptitude, and worked sometimes as a book-binder and sometimes as a hat-maker, and he was fifty years old when he chanced quite accidentally to see an announcement of the competition. Though he was no mechanic, Jacquard had spent much of his spare time in thinking out a machine loom for making lace. He set to work on a model of this machine, though without any idea of entering for the competition, for which he supposed the finest mechanics of the day would be entering designs. Fortunately, a fellow-workman to whom Jacquard showed his model had the sense to see that it embodied a very valuable idea, and asked to borrow the model in order to obtain advice on the matter.

It was not long before Jacquard received a summons to Paris. Full of forebodings, for the times were unsettled and men were often arraigned for crimes they had never committed, Jacquard set off and found himself before Napoleon. "Are you the man," he was asked, "who pretends to do what God Almighty can not do—tie a knot in a stretched string?" Jacquard stammered a reply that he did not attempt

to do what God could not do, but only what God had taught him to do. Thereupon Napoleon asked him to describe the working of his model, and Jacquard, soon gaining confidence, explained his plans.

Jacquard's invention was primarily designed for making lace by machinery. Its principle was very quickly adapted to solve one of the greatest troubles of power-loom weavers—the manufacture of figured stuffs, that is, cloths in which a pattern is woven. A simple pattern can be woven on an ordinary loom. The introduction of coloured warp or weft threads—or both—will, of course, produce cloths with stripes or checks. But complicated designs—figured damasks, such as are used for tablecloths, for instance—required such very skilful loom-mounting, as the work of arranging the heald-shafts is called, before ever the weaving could be started, that figured stuffs were very dear. And at the best, the number of healds that a weaver could operate was very small; nothing approaching the hundreds of different combinations of warp and weft threads required to produce complicated patterns.

A great textile authority has said that Jacquard's invention effected a complete revolution in the art of weaving, especially in the finer kinds

of figured silk fabrics. It was not in itself a weaving-machine, but rather an attachment capable of being adapted to any power-loom. Its particular function is to manipulate the warp threads for the passage of the weft exactly in the sequence required to produce any predetermined design. It is not easy to describe, and, to the uninitiated, incomprehensible when seen at work. But, in its essentials, it consists of a great number of hooked wires—one for every warp thread—the movements of which are governed by a revolving drum with square sides, each side of which is perforated with holes. The wires lift the warp threads, or permit them to remain unlifted, according to whether or not the perforations in the square-sided drum receive or reject the ends of the wires; while the interposition in front of the drum of moving cards perforated exactly in accordance with the required movements of the warp threads, makes possible the weaving of the most beautiful and complicated patterns. The function of the cards is exactly similar to that of the perforated paper rolls which control the sequence of notes in a barrel-organ or a player-piano.

More romantic than either cotton or wool, the silk industry has called for as much in-

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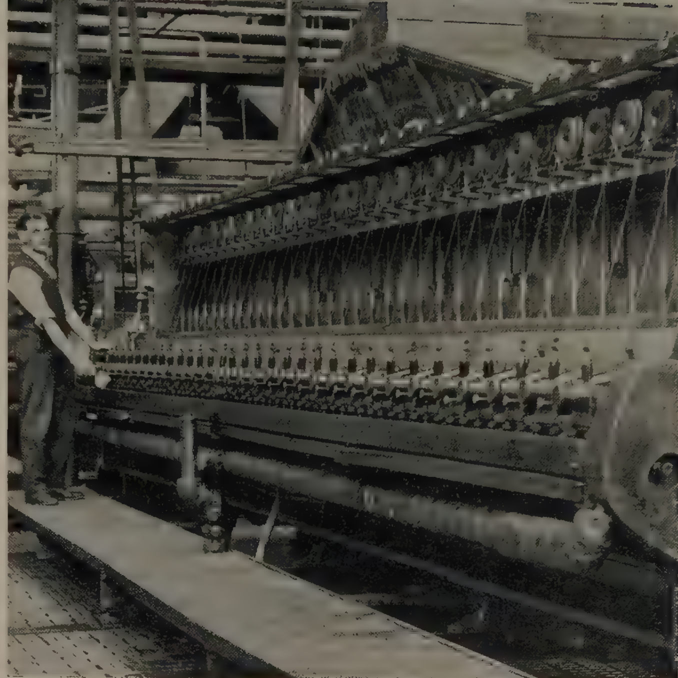
Showing the physical character of "Viscose" before spinning



By courtesy of Messrs. Courtaulds, Ltd.

"Topham Box" Spinning Machine in which the "Viscose" solution is converted into a fine continuous yarn

"RAYON" MANUFACTURE

genuity and perseverance as either. If we look up the word "silk" in an etymological dictionary, we shall find that it comes to us from a Greek root meaning a "native of China", showing us that China has always been famed for its manufacture of silk. The silkworm, indeed, is not a Chinese insect, but was found originally in the Himalayas and taken into China, where it was cultivated, though not at first with any idea of using the cocoons. At length, in the year 2640 B.C. the reigning queen, a lady named Se-Ling-She, found herself with plenty of time and little to do, so, much as fashionable ladies may take up Pekinese rearing to-day, she started a silkworm farm. If the writers of the time are to be believed, she discovered a means of unwinding the cocoons without breaking the thread, and she is also credited with the invention of a loom. At any rate, her husband, the Emperor Hwang-te, was so delighted with her industry and her silk that he had his own clothes made of it. His courtiers eagerly followed his example, and thus the silk industry came into being.

It was exclusively a Chinese industry, and the secret of the production of the silk was guarded with the utmost care, so the export of silks to the known parts of the world was a

most valuable asset of the Empire. But eventually the knowledge spread, and in doing so gave rise to wonderful tales of the adventures of those daring spirits who tried to discover the source of the mysterious substance. Perhaps the quest of the silk was as great an attraction in those days as Secret Service or Antarctic exploration is in these. That the dangers and difficulty of the quest were really great seems to be proved by the fact that silk manufacture was not introduced into Europe until five or six hundred years after Christ. In the Middle Ages, France and Italy were famed for the magnificence of their silks, which were manufactured by secret processes. At that time England was not very well advanced, and might have remained backward in the silk trade had it not been for John Lombe.

John Lombe was a silk manufacturer of Derbyshire who was dissatisfied with the limitations of his craft and longed to bring the English market into competition with the Italian one. Since, in spite of all inquiry and experiment, he could not succeed in improving his productions to the required extent, he devised a daring plan. Disguising himself as a workman, he travelled to Italy and obtained a post in one of the foremost silk factories. There he worked

for several years, and although, being a foreigner, he was viewed with some suspicion by his fellow-workmen and his superiors, he managed to learn all that he wanted to know of the Italian processes. Then he had to make plans for his escape, for the workmen—and foreigners especially—were all very closely watched, but by the exercise of caution and cunning he managed to reach an English ship lying in port and was conveyed home in safety.

From the moment of his return he set to work to reorganize his methods and to build looms of the same pattern as those he had operated in Italy. Before many months were over he was producing silk which, if not equal to the Italian, was at any rate much finer than anything previously made in England. The Italian agents reported this unexpected development, and ultimately the owners of the factory at which Lombe had worked discovered the trick which had been played upon them. One of their number was forthwith dispatched to England, and making his way to Lombe's house he found an opportunity of administering poison by way of revenge. Lombe died, but his works lived, and the Italians had to see a large proportion of their trade passing into English hands.

A further stimulus to the English silk manu-

facture was given by an invention of Mr. Lister of Bradford (afterwards created Lord Masham) for utilizing the floss, which is part of the raw silk that could not be used by the silk-spinning machines and was thrown out as waste. Lord Masham, in 1857, found a method for utilizing this waste and spinning and weaving it into the fabric known as " spun silk ", a very cheap and useful product which brought great profit to the manufacturers.

A great industry has been built up in artificial silk, cunningly described in many advertisements as "Art Silk", from which unsuspecting people think they are buying silk of an artistic shade or texture. The makers of this beautiful new material do not wish it to be misrepresented, and so it has been given the name " Rayon ". Although rayon is very strong and has a silky appearance it has no chemical relationship with real silk. It has virtues and uses all its own, and can be used to substitute or reinforce threads of any other material. It is, in short, a new factor in industry, and its story might well fill a book twice the size of this.

For many years inventors and scientific explorers had been attracted by the idea of a synthetic silk. Students of the spider and of the silkworm itself were led to the conclusion that

silk was only a gum which solidified after being forced through an orifice. It was supposed that sticky substances such as varnish could be drawn into thread, and many were the experiments made with that idea in view. The name of John Mercer, a Lancashire calico-printer and chemist, is a very important one in the history of rayon manufacture, not because of the lustre of "mercerised cotton", but because his discovery (in 1840 or thereabouts) of the chemical action of strong alkali on cellulose was the foundation upon which subsequent research has been built, leading ultimately to the invention of rayon. But the process known as mercerising was not Mercer's invention, but actually that of a Mr. Lowe. Mercer discovered the swelling action that caustic alkali had upon cotton. It was not until 1889 that Lowe discovered that if cotton was prevented from shrinking while the action of the caustic was proceeding, it gained new proportion, particularly an increased lustre. The process did not, however, become at all extensively used until 1895, some time after the brighter rayon fibres had been produced.

The next step followed in 1855, when a Swiss named Andemars devised a process by which nitro-cellulose could be "squirted"

into fine threads, and from this have sprung the various methods of rayon manufacture now in use. In the chapter on "The Age of Electricity" (p. 131) I touched on Joseph Swan's successful method of making filaments for his lamps from liquid nitro-cellulose. Indeed, Swan, foreseeing the value of Andemars' process, actually produced a woven fabric which was exhibited in London under the name of "artificial silk" in 1885. In the same year a Frenchman, Comte Hilaire de Chardonnet, took out a patent for making silk by the nitro-cellulose process. Following an exhibition of his work in 1889, the first "artificial-silk" factory in the world was built at Besançon. Other processes have followed: the viscose process discovered by two English chemists in 1892, the acetate, and the cupra-ammonium. Each of these has its special advantages, and many types of weaving have the weft of thread made by one process and the warp by another.

In 1891 de Chardonnet's factory attained an output of 12 tons of nitro-cellulose yarn. Thirty-five years later the world production of rayon was in the region of 120,000 tons a year—an indication of the rapidity with which the demand for the new material grew. The demand is still growing, and there is no doubt

that rayon will become economically as important as the other staples of the textile industries.

Cellulose, the basic material of all rayon, is an exceedingly interesting and complex substance. It is an elementary principle of plant-life, being formed in the living cells of plants, and varying a great deal in its characteristics. That is to say, the cellulose in the woody cells of trees is different from that found in cotton, and that again from the cellulose in the stalks of cabbages. Some forms are purer than others, or are more easily freed from objectionable substances, such as the gums and resins in pulped wood, which are absent from cotton-cellulose. It must not be supposed that the applications of cellulose to the needs of man are in themselves new. Gun-cotton is nitro-cellulose—cellulose treated with nitric and sulphuric acids. Celluloid is gun-cotton treated in a particular way to make it tough and resilient; and dissolved in ether, alcohol, acetone, or other solvents, cellulose forms substances to supply the special needs of many industries.

The cellulose used by the rayon manufacturers is obtained either from the small seed hairs called " linters " which remain on the cotton seed after the long spinnable hairs have been torn off by the gins. These small

hairs are washed, boiled, and bleached, and are finally formed into thick boards called pulp, in which form they are received at the rayon factory. Cotton pulp is used for all types of rayon, but many viscose yarns are produced from the cellulose of wood pulp, made from spruce or pine grown in the forests of Canada or Northern Europe.

At the pulping-mill the tree is reduced to chips and boiled with calcium and magnesium bisulphide, after which it is washed, bleached, pressed into sheets, and dried. After that, the sheets are steeped in a tank of caustic soda, and when they have absorbed the required amount they are ground up in toothed mills into "crumbs". The "crumbs", treated next with carbon bisulphide, find themselves turned into a gelatinous substance called xanthate, which in its turn is dissolved in water to be converted into "viscose".

It is for the treatment of the viscose, and the similar viscous solutions of cellulose produced in the cupra-ammonium and acetate processes, that chemist and engineer have joined hands in devising many beautiful and marvellously ingenious machines for forming, winding, and stretching the filaments of silk that weavers and knitters demand in constantly increasing quantities. The viscose is pumped into spinning-

machines, from which it issues through platinum nozzles perforated with minute holes. There may be a hundred spinning-nozzles to a machine, each with its scores of perforations which are sometimes as small as $\frac{1}{1000}$ inch diameter. As the viscose is forced through, into a bath of some coagulating liquid, it immediately forms as many fine filaments as there are openings, which are brought over wheels into a rapidly revolving box. Here, the many parallel filaments are twisted together to form a single thread, which, by centrifugal action, is wound into the form of a hollow cylinder. This is known as a " cake ", from which the rayon has afterwards to be wound on reels, or formed into skeins. Then come washing, bleaching, and the all-important dyeing, and the wonderful product is ready for its thousand and one uses.

CHAPTER VIII

The Age of Flight

The story of Icarus in Greek mythology is the typical story of the men who have tried to fly with wings of their own making. It could not be done. Science now teaches us the reason why. It takes a bird to pieces and shows us the hollow bones, made of amazingly light material; shows us the area of the spread wings, so large relatively to the weight of the body between them; and proves to us how impracticable would be the wings large enough to lift ten or eleven stones of manhood. Man was never "built" for flying by his own strength. It is believed, moreover, that birds profit enormously by air-currents moving in an upward direction. Observers in India declare that birds cannot hover or soar until two or three hours after sunrise; that is to say, until the earth is sufficiently warm for currents of hot air to rise from it. Another widely accepted theory is that the ears of birds are not provided for hearing the grossly audible

sounds to which human beings listen, but for detecting the peculiar sounds of upward-rushing air-currents, and that the birds glide from one to another of these with the expenditure of very little muscular effort.

Records are preserved of many early attempts at flight, but although some of the early adventurers actually succeeded in flying—or more probably gliding—short distances, none of the appliances used survived or were improved upon for further experiment. When, in 1766, it was discovered that hydrogen, known at that time as "inflammable air", was seven times lighter than atmospheric air, would-be aeronauts had an entirely new idea to work upon, but their first difficulty was in finding a material which would contain the gas and yet add little to the weight. Joseph and Étienne Montgolfier, of Annonay in France, bethought themselves of making an artificial cloud by sending up a paper bag filled with hot smoke. This proved a very amusing experiment, and after a good many tests a public display was arranged in 1783. This attracted a great deal of attention, and large crowds assembled to witness such an entirely new spectacle. The balloon itself was made of linen lined with paper, of a capacity of 23,000 cubic feet. When a fire of chopped straw

was lighted under the opening at the bottom, the bag gradually filled with hot air, and the balloon rose to a height of 6000 feet. It can be imagined that the philosophical and scientific world was greatly interested in the demonstration, and as a direct result a M. Charles, of Paris, started to make a gas balloon. This balloon was completed about a couple of months after the Annonay demonstration. It was a tiny affair compared with the first, being only thirteen feet in diameter. It was filled with hydrogen and was sent up from the Champs de Mars, to the astonishment of a great concourse of people. On this occasion the balloon soared up out of sight, and finally came down at a spot fifteen miles from the starting-point. Two months later a balloon made by the Montgolfier brothers was used for the first ascent by man, a M. Pilâtre de Rozier going up in a captive balloon.

M. Charles was still working on his hydrogen balloon, and with a friend he made an ascent lasting nearly two hours. His balloon was provided with a valve and also with bags of sand as ballast, and after landing and disembarking his friend in safety M. Charles reascended alone and reached a height of 10,000 feet. By this time interest in the new means of progression had spread to other countries. The first reputed

ascent in Great Britain was made by J. Tytler in Edinburgh in 1784, and Vincent Lunardi, secretary of the Neapolitan Embassy, was the first man to " go up " in England. The following year, the first balloon flight across the Channel was successfully carried out from Dover to France. Pilâtre de Rozier then ventured to cross in the opposite direction. He sought to improve the design of his balloon by combining the two patterns then in use, that is to say, he put a hot-air compartment below the hydrogen bag, with the inevitable result that the hydrogen quickly burst into flames and de Rozier and his fellow-passenger were killed.

Several disasters followed; but both men of learning and men of action were now alive to the possibilities of ballooning, and longer and longer flights were attempted. About the middle of the nineteenth century Charles Green made the experiment of filling his balloon with coal-gas, with excellent results, and this innovation reduced the cost of ballooning so much that it rapidly became more popular. Great heights were attained, the record being a little over 30,000 feet; while in distance 1200 miles is believed to be the farthest ever travelled by a balloonist in one trip. But the balloon had no chance against the dirigible airship or aeroplane,

The dirigible balloon fascinated many inventors before the internal-combustion engine arrived to make it a practical possibility. A balloon was, indeed, constructed to be driven by a steam-engine turning a screw-propeller, but as the heaviest engine that could be lifted was of only three horse-power no very great development ensued. During the 'eighties France devoted a great deal of thought to the production of a dirigible balloon which should be of military value, and in 1885 Colonel Renard designed an airship driven by an electric motor, which was built by the French Government and successfully performed many trips in and around Paris. Some years later came Santos-Dumont, who made several dirigible balloons of a small type. But the great and enduring work of dirigible-balloon construction was that carried out by Count Zeppelin.

While Germany was building her navy and training her great army, one of the loyalest of her sons was straining every faculty to give her also military supremacy in the air. This was Count Zeppelin. He was convinced of the practicability of his own ideas, and when his first airship met with disaster he started at once to build another one. Airships are expensive hobbies. The great bag, composed of thousands

of square yards of fine silk, may be wrecked and torn beyond repair in a few minutes. Millions of cubic feet of valuable hydrogen can be irretrievably dispersed, while the light metal framing crumples into an unrecognizable mass at its first encounter with anything more solid than a cloud. Count Zeppelin was not a very rich man, but by disposing of all his property he was able to realize about £30,000. With this sum he went to work again and succeeded in obtaining the recognition of the German Government, after many years of toil and disappointment and endeavour. During the War airships of his design and called by his name were in constant use, and though they did not carry out the work of wholesale destruction which their country expected of them, they were undoubtedly of service.

Interest in Zeppelins revived with the Atlantic voyage in 1928 of " Graf Zeppelin ", the 127th of her name. To the German people, this success was a matter of heart-felt rejoicing. Four years earlier a German-built airship, the ZR3, was piloted across the Atlantic by Dr. Eckener, the captain of " Graf Zeppelin ", and handed over to the American authorities on reparations account. It was renamed " Los Angeles " by the Americans.

The voyage of 1928 was a memorable one for reasons other than sentimental. It was, both in distance and duration, the longest voyage ever achieved by an airship, having occupied 112 hours in covering a distance of 6000 miles. The journey was increased by the long detour made by Dr. Eckener to avoid a bad storm raging over the Bay of Biscay, information of which had been wirelessed to the ship. But in spite of this a storm was encountered which damaged the horizontal fin of the airship. This damage had to be repaired at once, and the speed of the vessel was reduced to fifty miles an hour in order that she might be kept on a level course, as any undulation might have resulted in the remainder of the fin blowing away. Four of the crew had to climb out on the rib of the airship and patch the damaged area with blankets sewn together—five hours' work in a raging storm. Wireless communication with Germany was maintained throughout the voyage, and at the great moment of landing at Lakehurst the broadcast description was relayed from Stuttgart in order that the thousands of expectant people who travelled in spirit in "Graf Zeppelin" might share in the triumph.

One of the most interesting features of "Graf

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By courtesy of *The Times*

THE STATE AIRSHIP R 101

Showing the girder-work inside the hull and one of the gasbags inflated

Zeppelin" is the successful adoption of a new fuel for the engines. Blaugas, as the fuel is called, is a gas distilled from crude oil during its decomposition in retorts at a temperature above 1000° F. The gas is practically as light as air and is stored in a special fuel-compartment in the gas-bag of the giant dirigible. The advantage of a fuel of so little weight that it does not necessitate the wasteful dispersal of precious hydrogen as it becomes used up is so obvious that it need not be laboured. But against this must be set the disadvantage of inflammability as great as that of petrol. On this account British designers are not particularly impressed by blaugas, pinning their faith rather to heavier engines propelled by heavier but less dangerous fuel.

In the case of the great British dirigible R101, intended for flights to Australia, India, and Egypt, heavy-oil Beardmore Tornado engines are used. I said something about these engines on page 174. Five of them, each of 580 horse-power, supply power for R101, which is a very much larger vessel than "Graf Zeppelin". Dr. Eckener himself has admitted that his ship of 3,750,000 cubic feet is not big enough for very long voyages. Although R101 has a capacity of 5,000,000 cubic feet—larger than the

Mauretania, though not quite as long—it is astonishingly light. This remarkable lightness is due to the special structure of the framework, composed of girders made of the very thin but immensely strong steel tubing I spoke about on page 53. The passengers' quarters are furnished with luxury and elegance, and yet the total weight of the huge ship is to be no more than 150 tons when fully loaded. Every possible means of weight saving has been adopted. A special "featherweight" metal is used for all the furniture, and even a lightweight paint has been provided for the interior of the whole structure. R101 embodies a great many new features, most of which are directed towards reliability and safety from fire. There is a total length of 1500 feet of fuel-pipe running through the hull, and over 500 feet of water-pipe. Electricity, of course, provides the lighting and cooking medium. But the outstanding development in fire-protection is the adoption of a flame-stopping device for which it is claimed that it will check the passage of flame even in highly explosive mixtures.

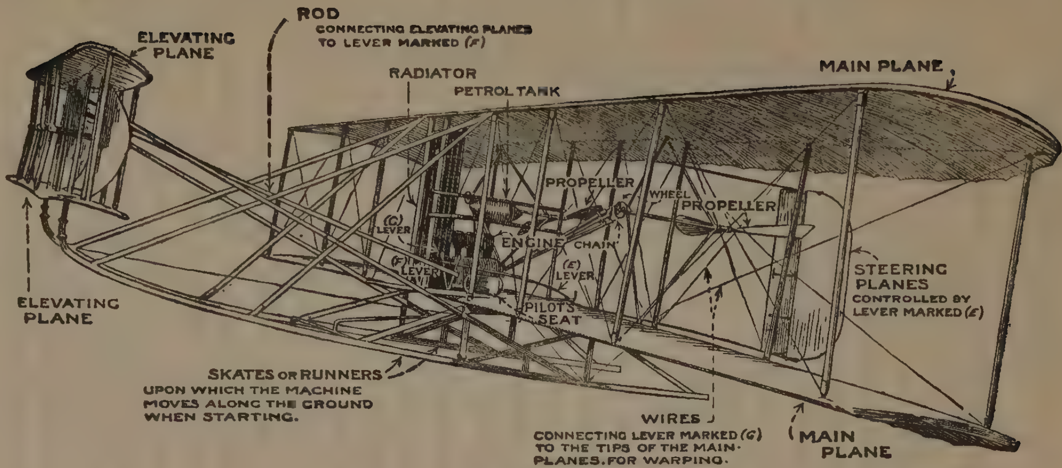
Another great danger of airship flight occurs from the vertical air-currents which associate with thunderstorms. It is easy to understand that alteration in the altitude of an airship

results in alteration of the gas pressure inside, and any rapid rise or fall of the external pressure may have a serious effect if the internal pressures cannot automatically adjust themselves. The airship "Shenandoah" was wrecked by an upward gust which was estimated to be travelling at 2000 feet a minute, and in order to prevent any such catastrophe overtaking R101 special automatic pressure-valves capable of equalizing a vertical current of 4000 feet a minute have been designed. Thus the fifty fortunate passengers who sit down to dine in the saloon of R101 may do so with confidence that everything possible to ensure safety has been incorporated in their vessel, and they will even be allowed to smoke—for the first time in any airship—in a specially constructed smoking-room.

Simultaneously, R100 is nearing completion in the sheds of the Airship Guarantee Company at Howden. This has accommodation for a hundred passengers and a crew of fifty, and is driven by six Rolls-Royce petrol-engines totalling 4200 horse-power, which are housed in what are called the "power eggs" right at the rear of the airship, where their roar cannot disturb the sensibilities of the passengers. Dynamos for generating light and heat are also in the power eggs. It is expected that R100 will be able to

fly to India in four days, to Canada in three, and to Australia in a week, but the present intention is to use her for transatlantic service. She is regarded almost in the light of a preliminary experiment, as, if she fulfils the requirements and expectations of her designers, the next large airship to be built will have a cubic capacity of 9,000,000 feet and will be capable of carrying 200 passengers to America in thirty-six hours.

While one school of aviators was experimenting with lighter-than-air machines, another was devoting its energies to the heavier-than-air machine, as typified by the glider. The glider was, in effect, a light wooden structure carrying canvas sails, or planes. The operator carried his glider to the top of a hill and then, taking his position in the machine, would float gently down. Orville and Wilbur Wright, cycle mechanics of Dayton, Ohio, were the pioneers of flying. The brothers spent years at work on the glider, and from their observations of the behaviour of the glider they slowly but surely built up the theories which they afterwards embodied in their first motor-driven glider—the forerunner of the aeroplane. By practising continually they learnt enough of the laws of stability to enable them to attach a small petrol-



The Wright Biplane

engine to a glider, and in 1903 they flew by this means a distance of three hundred yards. This was success, and having flown so far it was only a matter of perseverance in further experiment to achieve prolonged flight. Fortunately the Wright brothers were possessed of any amount of patience, and within two years their machine flew twenty-four miles. Up to this time their experiments had been carried out privately, but so important an event as this could not be hidden, and the Wrights' home on the coast of Ohio was besieged by the curious and incredulous as well as newspaper reporters. This sudden notoriety was almost more than the newly born flying-machine could stand, and so much ridicule was directed at it that less confident inventors might have been tempted to abandon their attempts.

There followed several years of feverish and often misdirected effort. "Flying Weeks" became very popular, notwithstanding that during these displays not a few valiant adventurers lost their lives. Races and competitions, cross-country and cross-channel flights were organized, to which competitors flocked from all parts of the world. Presently came the establishment of aerodromes in England, France, Germany, and America, where experimental

flying was in constant practice. Then came the War.

On 25th August, 1919, when the needs of the civilian world once more could be considered, a small aeroplane of 360 horse-power, carrying two passengers, announced itself as the first daily air-service between London and Paris. "How long will that last?" asked the wiseacres. To their surprise it did last, and the little machine faithfully made its return journey daily, and during the first week of its duty carried twenty passengers and several parcels. From this small beginning has developed the great concern known as Imperial Airways, which, week by week, conveys over two thousand passengers to and from the Continent, while the cargo traffic has increased to as much as 50 tons.

Extraordinary efforts are being made to render flying safe, and to a large extent this has been achieved, although the most potent factor in flying—the weather—can never be controlled. The great majority of flying accidents occur on account of "stalling"; that is to say, the engine suddenly loses power, generally by reason of some unexpected wind-current. An attempt to overcome this is the adoption of slotted planes, which have the property of maintaining the equilibrium of the machine longer than the flat

pattern. Of equal importance is the rigorous testing of pilots, which—so far as British flying is concerned—is carried out every six months under rules laid down by the Central Medical Board of the Royal Air Force. It is this policy which is largely responsible for British freedom from accident in commercial and civil aviation.

The danger already referred to, the tendency of a machine to " stall " if the engine loses power too quickly, and consequently to fall earthwards in an uncontrollable " spin " or " nose-dive ", has led many inventors to attempt the solution of the difficult—if not impossible—task of maintaining an aeroplane in the air by utilizing vertical propellers. The function of such propellers, called helicopters, would be to support the weight of the machine independently of the tractor propeller and the supporting wings. The helicopter idea goes a very long way back in the history of flight; it is so attractive—and so simple; for the vertical lifting apparatus should provide such an easy and practicable means of rising, descending, or even remaining stationary in the air. Unhappily, the mysteries of aerodynamics have in the past proved too much for the helicopter theories, and the enthusiasts have come to grief. But it may be said of the young Spanish inventor Juan de la

Cierva that his autogiro, or " windmill plane ", is one of the great hopes of the future. It has emerged successfully from test after test, it has survived demonstration after demonstration; and perhaps the greatest promise given by de la Cierva of the ultimate triumph of his invention lies in the fact that his windmill planes have crashed time after time, without injury to anyone.

The autogiro has no planes, in the usual sense. There are ailerons, rudder and elevator, controlled as in any ordinary aeroplane, and a tractor propeller, driven by an engine of moderate power. The special interest of the machine lies in the windmill planes, which, mounted on an upright mast above the machine, are free to revolve to the air-currents created by the propeller. These lifting vanes or " rotor planes " are also hinged, so that they are capable of slight upward and downward movement. The vanes are feather-shaped, their size and form being the outcome of intensive scientific study. The air strikes the feather-edge of the vanes, and by repelling them causes the windmill to revolve. In turning against the wind pressure the vanes exercise a very powerful lifting influence; and this lifting effect being equalized by the slight vertical flap—not unlike the movement of a bird's wings—permitted by

The Cierva Autogiro in Flight

the hinges, gives to the machine a very unusual measure of stability. In fact, the autogiro is genuinely self-balancing. It cannot "stall" or nose-dive; air-pockets or "bumps" leave it uninfluenced, and its passengers are therefore immune from air-sickness.

The autogiro is still very young. Señor de la Cierva did not publicly demonstrate his first machine until 1923, and it has yet to be improved in various ways. For one thing, it cannot take-off in a direct upward lift. Although it takes the air with a much shorter run than an ordinary machine, it is still necessary to taxi [1] until a sufficient speed for the rotors has been reached. This prevents the autogiro from rising in a very confined space, although it can

[1] In case you do not know, in flying jargon this horrible word denotes the run necessary for an aeroplane to attain sufficient speed to lift the landing wheels off the ground.

alight in a vertical direction in little more room than is occupied by its own bulk. And very pretty it is to see the windmill plane hovering like a gigantic hawk just before it makes its easy, bird-like swoop to the ground.

The Age of Flight is barely ushered in. Only a quarter of a century has passed since the Wright brothers looked towards it from their little hill in Ohio; not much more than a life-time since Sir George Cayley (whose name we remembered in The Age of the Heat-engine) foretold its coming. All honour to the brave pilots—of to-day as well as of yesterday—who have won the mastery of the air. But let us not forget those other pilots, in laboratory, drawing-office, foundry, and workshop, without whom no mastery could have come. Flight is the engineer's job—his and the metallurgist's. New materials for frames, always lighter and stronger; new engines, lighter, faster, capable of roaring on, hour after hour, with never a missfire, never a broken valve-stem—those are the things that have secured the real mastery. Paring down weight till it is less than 2 lb. a horse-power, speeding up movement till there are 4000 revolutions a minute—only the engineer can tell you of the real triumph of such accomplishment. He only knows the difficulties.

CHAPTER IX

The Age of Wireless

Of all the applications of modern science, few have made their way so rapidly into the homes of the world as that which we loosely term "Wireless". As soon as wireless receiving sets for the small household became a commercial possibility and broadcasting stations were provided, the gardens of all nations suddenly sprouted poles, and thousands of miles of wire were almost instantaneously transformed into aerials. It was a startlingly sudden development of a natural law which had been recognized many years before. Faraday, and after him Clerk-Maxwell, had propounded a theory of the existence of electric waves in the air, and their work was carried on by Heinrich Hertz, who, in 1888, proved the correctness of Faraday's theory and discovered that such waves could be set in motion by an oscillatory electric spark, such as can be produced at the secondary terminals of an induction coil.

One of the most bitter controversies in the history of invention has centred round the discovery of Hertzian rays. And to get to the bottom of it we must trace the story of the telephone, when we shall find that, instead of the idea of wireless transmission of electric signals being something quite recent, the idea was in reality the outcome of very early experiments with devices for converting sound impulses into electrical impulses. There is no doubt whatever that a London scientist, Professor D. E. Hughes, while working upon the telephone microphone, conceived the idea that electric waves might operate as well as an electric current in a circuit, and his was the first attempt at wireless telephony. But let us break off for a moment to see how the telephone came into being.

In the early seventies of last century, a young Scots-Canadian named Alexander Graham Bell was deeply concerned in the welfare of the deaf, and had achieved a considerable amount of success in the difficult task of teaching the deaf to speak. As a further development he was anxious to find some means of acquainting them with the speech of others, and he set to work to make speech *visible*. Such an idea was, of course. entirely outside the realm of practical

thought in those days, and he had nothing to guide him beyond his own researches and his intense desire to help the unfortunate people amongst whom he worked. After much consideration, Bell took two electro-magnets, placed them at a short distance apart, and connected them in a circuit. He fixed a slender iron disc in front of the first magnet and another behind the second. Then he spoke against the first disc. As he had hoped, the disc vibrated and the vibrations were picked up by the magnet, which transmitted them through the wire to the second magnet, this in turn operating the second disc. Thus the sound-waves of his voice were transformed by the first magnet into electric impulses, and by the second magnet were resolved again into sound-waves.

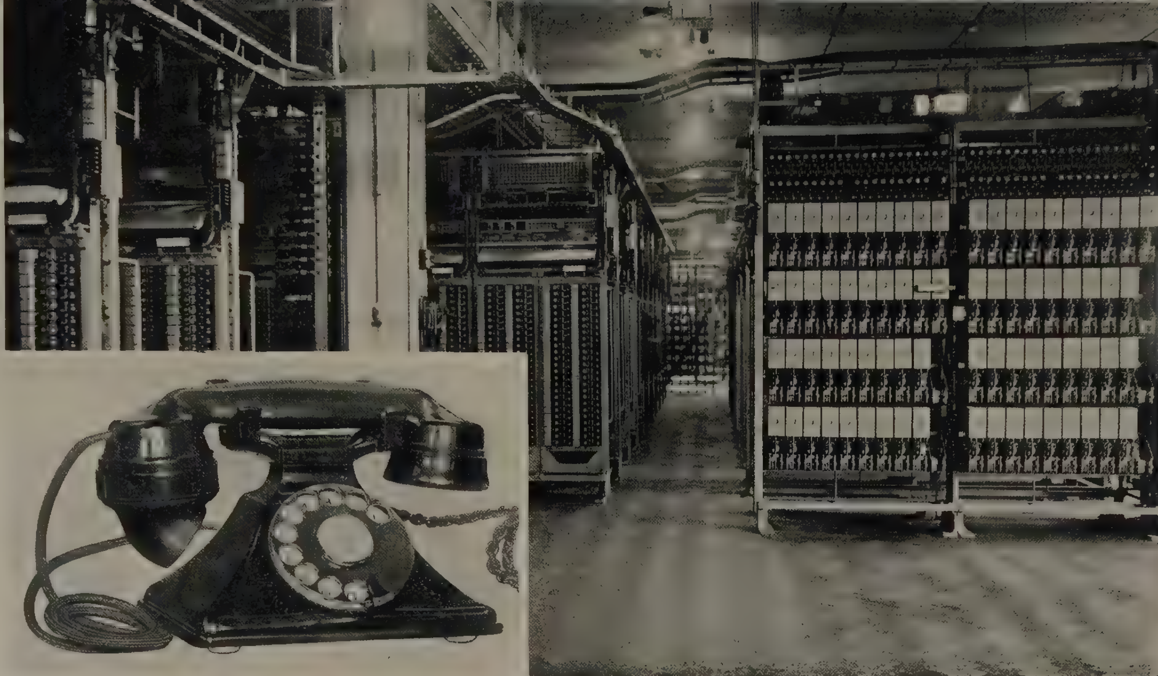
This, of course, was putting a totally different line of investigation before him. To what distance, he wondered, could his magnets be separated, and still carry the sound of his voice? To this question no one could give him any answer, and all whom he consulted pooh-poohed the idea altogether. But he was fired with enthusiasm for his project, and throwing up all his other work, devoted himself to the perfecting of his instruments. He was able to find a niche for himself in a Boston workshop,

and there he laboured and toiled, often, we may be sure, to the point of despair, for forty long weeks; until at last, one day his voice reached his friend sitting in the basement three floors below. "Come here, Mr. Watson, I want you," was the apparently insignificant message which told of success. Mr. Watson, no less excited than Bell, ran up the stairs and burst into the room. "I heard you, I heard you!" he cried joyfully; and on his twenty-ninth birthday Bell applied for a patent for his invention.

Bell's instrument was of little use except as a brave experiment. One of the men of science impressed by its possibilities was Professor Hughes, whom we encountered a few pages back as the true discoverer of electric waves in the ether. Hughes realized the imperfections of Bell's arrangement, and it was he who, by the invention of the microphone, rendered the telephone of immediate practical utility. In Bell's telephone the current was induced by the voice of the speaker vibrating a magnetized disc; in the Hughes system (and also in Edison's, which, invented almost simultaneously, is the same in principle) the current is produced outside the circuit, the voice of the speaker being simply the means of controlling it. To put Hughes' problem very shortly: how could he

make the vibrations set up by the speaker's voice control a sufficiently powerful electric current to energize a thin disc or diaphragm at the listener's end to the extent of making it reproduce the original sound vibrations?

The outcome of the problem was the invention of the beautiful little device known as the microphone. Hughes (and, quite unknown to him, Edison also) decided that there must be in the circuit some substance that would normally keep the current shut off. What was required was an automatic switch, as it were, that would not merely allow the current to flow or shut it off, but would be capable of opening and closing the circuit in sympathy with the infinite fluctuations of speech. Well, both Hughes and Edison found in carbon the most suitable resistance for blocking the current. Edison employed a film of lamp-black; in the Hughes microphone some tiny granules of carbon placed behind the diaphragm prevent current from passing, until, in response to the vibrations set up in speech, they cling together, or "cohere", in greater or less degree. The more the granules cohere, to that extent is their electrical resistance lessened, and they thus permit the passage of a fluctuating current which energizes an electro-magnet in the receiving instrument and causes it to vibrate



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Reproduced by courtesy of Messrs. Siemens Brothers & Co., Ltd.

THE AUTOMATIC TELEPHONE

A view of the interior of the Western Exchange, London. The inset shows Siemen's Neophone or automatic table telephone

a thin metal diaphragm to recreate the original sound-waves exactly in sympathy with the fluctuating current.

So much for the microphone—and the coherer—that remarkable little instrument that owes its action to the great variations of resistance of two electrical conductors—a good and a bad—in loose contact. And to my way of thinking, the story of the telephone is none the worse because it destroys the illusion that sound-transmission without wires is an entirely new thing.

There is no doubt whatever that David Edward Hughes was "broadcasting" speech in Portland Street, London, several years before the great Hertz had made and measured electric waves, and at a time when Marconi was an infant. It was not chance or accident that led Hughes to believe that electric waves might operate the telephone as well as a current in a closed circuit, but deductions arising from his researches. He devised instruments that clearly demonstrated that speech was possible "by wireless" over a distance of several hundred yards, but the scientific experts sitting in judgment on him declared the thing to be impossible, and the discouraged inventor gave up his experiments.

Many useful and ingenious inventions have followed those of Hughes to bring the telephone system to the ubiquitous and indispensable service it now provides, but none is more interesting than the wonderful invention of three Canadian brothers named Lorimer. This was the automatic machine which takes the place of human operators at the telephone exchanges. The automatic exchange was a commonplace in America before the first experimental exchange was equipped in England, and it has only very lately been put into operation in London. There are now several systems at work, some power-driven, some actuated by the ordinary telephone circuit, but they are much too complicated to be made plain without a great deal more explanation than is possible here. The automatic exchange is so extraordinarily ingenious, however, and an invention of such great public utility, that I must try to give you a bald idea of how the type works that is now in use in London.

I do not need to tell you that in the ordinary telephone exchange each subscriber's line is connected with a plug-in contact on a huge switchboard, divided into sections, each with a convenient number of contacts—some hundreds of them—for a single operator to mani-

pulate. The operator's function is to connect, by means of a short length of detachable cable, any two contacts on her section, or any contact on her section with any on another section. In the automatic system the contacts are made by a power-operated "selector", the impulses controlling its movements coming from the subscribers who want connexions. Even electrical engineers, unsusceptible to marvels that impress other folk, admit that there is an uncannily human power in the device that seeks for and finds the necessary contacts in the automatic exchange. To each subscriber's instrument is attached a dial with movable letters and numerals. To get in touch with the exchange he wants, the subscriber moves three letters on the dial. An electric impulse travels to his own exchange, where there are ranks of contacts arranged in semicircular groups, each group being controlled by a moving metal arm driven by a little motor.

Suppose you watch its working while I "ring up". I move my three letters, to get through to the subscriber to whom I shall speak. You see an arm in one of the semi-cylindrical groups of contacts spring into action; it finds at once the correct exchange connexion, and opens the way to the next series of contacts. I now move the

numerals on my dial, first the thousand figure, next the hundred, then the ten, and so on, until I have picked out the telephone number I want to call. And as I do so, you see another arm spring out to find the correct thousand-figure contact. As soon as it is in position, the message is passed on to the next group of contacts, where another arm finds the hundred-figure contact and passes on the current for the next group of contacts, the tens; until finally I have made five arms search for and find the way for my message, out of the thousands of possible connexions they might make. All the contacts are on, and you hear a buzz that tells me the line is clear for me to speak; or perhaps you hear the high singing note that informs me that the number is engaged, or, it may be, a continuous burr that announces that the desired number is out of order. And if I were to muddle things by "dialing" incorrectly, or stood hesitant with the receiver in my hand, you would see the machine shine a light to call the overseer to my assistance. As soon as my call is finished and I ring off, the five arms fly back out of action, and in so doing they register my call so that it may be charged to my account. Altogether, you will agree, a very pretty and competent piece of machinery

So much for the telephone. Let us now go

back to the stage, fifty years ago, at which Professor Hughes abandoned his experiments in "wireless". Heinrich Hertz, in 1888, developed the theory put forward by the great English electrician Clerk-Maxwell, that electro-magnetic waves were closely akin to light-waves. It was already believed that all space, between star and star, sun and planet, as well as between the particles or atoms of matter, was filled with a something known as ether. This can be set quivering or vibrating, and the light and heat which reach us from the sun are really waves or vibrations in the ether. Hertz demonstrated that the electro-magnetic waves are propagated with a velocity equal to the velocity of light; he also showed that oscillating electric currents set up vibrations in the surrounding ether, just as the beat of a drum or the jangling of a bell set up vibrations in the surrounding air. An experimenter working in Paris, Professor Branly, invented a coherer much on the same lines as the microphone of Professor Hughes, and then when Professor Righi, of Bologna, invented a new type of sparking-machine, the necessary elements of wireless telegraphy were before the world, but under foreign sponsorship. If only our scientists of the 'seventies had been gifted with keener imagination, Hughes might have pursued

his investigations to a triumphant end, and "wireless" would have put a girdle round the earth at least ten years earlier.

Guglielmo Marconi was a student under Righi, and in 1894, when he was twenty years of age, he began seriously to work at the problem of wireless telegraphy. The knowledge he had acquired taught him that the waves named by Hertz short "free" waves quickly became very weak, and were, indeed, undetectable at a distance of two miles from their starting-point. His first task was to improve the transmission and receptive power of his instruments. Of course, he was much handicapped by ignorance of the nature of electro-magnetic waves. Nobody knew, at that time, that the incalculable electric force rushing down the ether from the sun absorbs the waves propagated by a spark transmitter. To get a rough idea of what was happening to the short waves Marconi and his colleagues were sending out, imagine yourself throwing stones into a pond during a violent hailstorm and trying to follow the ripples made by the stones! It did not occur to Marconi to try the effect of transmission at night, but day after day he went on with his attempts to signal from Cornwall to Newfoundland. Now and again the longed-for sounds would be heard—

often enough, indeed, to maintain the perseverance of the young inventor. It was fortunate that he was making his attempts during the winter of a northern latitude, for in Newfoundland there is so much fog and cloud during the winter that the rays of the sun were well blanketed. But by the year 1907 a thoroughly efficient public service of wireless telegraphy was established between Ireland and Canada, and since that time stations have been erected all over the world.

The subject of radio-telegraphy is sufficiently fascinating to the popular imagination—in spite of its abstruseness—to have acquired for itself a mass of non-technical literature, small doses of which, taken at regular intervals (preferably after meals), I prescribe for such of my readers as may be suffering from a muddle-headedness about the why and the wherefore of wireless. But I wish, before we leave the subject, to draw their attention to the very significant development that occurred in the summer of 1928. It has been known for a long while that (subject to certain " ifs ") waves stimulated in the ether could be utilized, when properly controlled, to operate all kinds of machinery many miles away from the point of control. Example. the voyages of travelling machines—trains

ships, aeroplanes—might be made entirely automatic and freed from the fallibility of human pilots. All sorts of unpleasant tasks occur to our minds that were better done by a distant force. The first really practical demonstrations of how wireless may one day be made to do for us what we dislike doing for ourselves came from the seemingly fantastic accounts of the manœuvres of the wireless-controlled German warship *Zähringen*. And not the *Zähringen* only, but the British target-ship *Centurion*, and doubtless others whose exploits have been less well sounded, have wireless "brains" capable of carrying out orders from control-ships miles away.

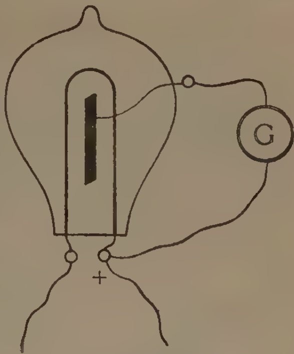
They have no crews, these ships. All the functions for which the hands and brains of many hundreds of men are normally needed are done automatically and mechanically. They can receive a hundred orders on their hundred aerials, and these orders are retransmitted by relay instruments, in accordance with their special purposes, until they become capable of performing, unerringly, many hundred different functions. The engines are stopped and started at will, cooled and oiled, and tended to the least of their multifarious auxiliaries; the boilers are fed with liquid fuel;

the ships are steered and manœuvred without a helmsman; the speed increased or diminished. Like the Ancient Mariner's ship of death, these new wireless ships, these huge steel boxes of machinery that need twelve thousand horse-power to drive them, are moved by an unseen force. There is not a living soul aboard them, yet every order received by their aerials is repeated to the control-ship, and an intimation is sent that the order has been carried into effect. And if they suffer injury or accident, they immediately heave-to and send out signals of distress. If these ships give you food for thought, remember they are but a beginning.

Of all the wonders of wireless the most astonishing is surely the thermionic valve. In wireless telegraphy it is both transmitter and receiver; it is the very base and foundation-stone of "broadcasting" in the popular sense; it is rectifier and amplifier in long-distance telephone circuits. And it is much more than that, the physicist will tell you. He will tell you that it is such a sensitive and adaptable recording agent that he is using it more and more for subtle measurements. Light, heat, the radiations of the stars, vibrations in buildings and bridges, the scarcely perceptible difference in a piece of sound metal and a piece with

the slightest flaw—the valve will measure and record the infinitely little and the awkwardly big in a new and highly important way. It is not too rash to say that of no other single invention is it possible to foresee so wide a range of probable applications for the benefit of mankind. Its use in wireless is barely twenty years old; the discovery of the mysterious property by which it functions was made no farther back than the early days of incandescent electric lamps.

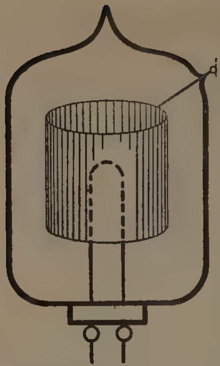
All the pretty shining valves in the wireless shops date their ancestry from experiments by Edison. The inventor had no thought of wireless, nor indeed of the possible outcome of his experiments, which had to do with the improvement of vacuum electric lamps. It so happened, however, that he made a lamp with a little plate of metal fitted in the space between the " legs " of the filament; to this plate a wire was fastened and led through the glass bulb. Now, when Edison connected this wire and the positive terminal of the lamp through a galvanometer, the latter indicated a small current. Very strange; for, the plate being quite free from the filament, there was no electric contact. Yet the current clearly passed from the filament to the plate. Several scientists investigated the pheno-



Edison Effect
G is a galvanometer

menon of the lamp, which was called the "Edison Effect", among them being Professor J. A. Fleming, of University College, London. It is to Professor Fleming's researches that the "Edison Effect" developed into the extraordinarily useful thermionic valve.

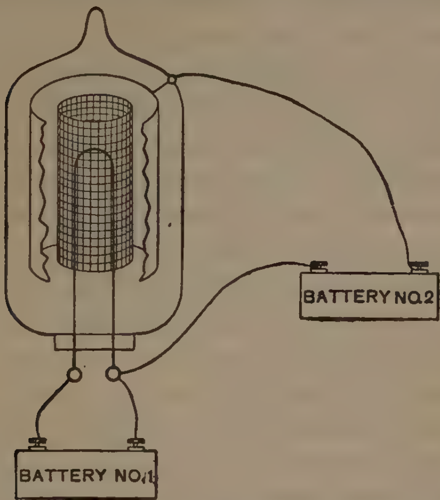
A valve, of course, is a door that can open to admit a thing in one direction only. But thermionic? Well, *thermos* is heat and *ion* is a wanderer, and there you have the meaning of the pleasant word. For the wanderers are electrons, the apparently indivisible and incredibly minute particles of *negative* electricity. They appear to wander around the skirts of atoms ready to rush out to restore the balance to a positively charged object. Heat increases their activity enormously. When the filament of a lamp is made incandescent, there is an outpouring of these particles of negative electricity. A plate inserted in the lamp, as in Edison's case, provides them with a gathering-ground. Now, if the plate is con-


Original Fleming Valve, 1906

nected to the positive terminal of a battery, there is a rush of these free negative particles to the positive pole, and, of course, a current. But suppose we reverse that; suppose we connect the plate and the negative pole of the battery. Obviously, nothing happens. Like repels like, and there is already an excess of negative electricity. Thus we have a valve; for the current can only pass in one direction; and if we send into the valve an oscillating current such as that received in a wireless aerial, you can see that it must emerge as the continuous current necessary to operate the purely telephonic part of our wireless apparatus.

In the modern valve there is a third pole or "electrode" connected with a gauze "grid" surrounding the plate. This grid checks the passage of the negative electricity emitted from the filament—and so becomes absorbed with a negative excess that stops the current from the plate. A positive charge from the battery relieves it of this negative excess, and the current again flows. You can understand now, I think,

how the valve works. The grid being connected with the receiving aerial, the incoming waves from the transmitting station bring to it alternately an excess or a deficiency of negative electricity. When there are too many negative



The Valve with the Gauze Cylinder (grid) as added by Dr. Lee de Forrest in 1907

particles in the grid, the current cannot flow from the filament to the plate. When there are too few, the valve is open until the difference in potential is once more restored.

There is a very strong affinity between the three-electrode valve and the light-sensitive

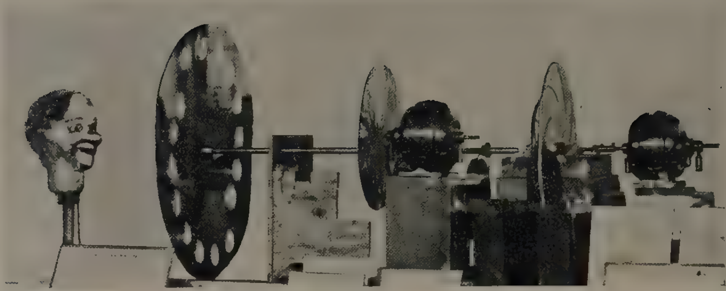
electric devices called photo-electric cells. The valve depends on heat for the emission of electrons; the photo-electric cell produces the same phenomenon by the action of the shorter and more rapid vibrations in the ether that we recognize as light. It is still more actively influenced by the invisible vibrations beyond the violet end of the spectrum, a discovery made by Heinrich Hertz as long ago as 1888. When he was making his famous Hertzian wave experiments, he discovered that the waves created by the sparks from his instrument passed more readily when waves of ultra-violet light lay across their path. It was later found that light could produce electricity by the emission of streams of electrons from the surface of a metal plate in a vacuum, or from the metal coating on the inside of a bulb or " cell ". The current produced by such a cell when light falls upon it is very, very small, but the action is instantaneous; a flash of a millionth of a second duration is sufficient for the cell to detect the light.

The photo-electric cell is of great interest to physicists. Its use has enabled astronomers to detect the light from stars that would otherwise have remained undiscovered; but its importance to our story lies in its application to the science of television.

The idea of seeing at a distance is a natural corollary of the idea of hearing at a distance. But technically it presents a much more complicated problem, for it is far more difficult to translate the appallingly rapid waves of light into electrical impulses that must then be translated again into light-waves, than to do the same thing by the slow air-vibrations that tickle or torture our ears. The length of light-waves—that is, the distance from crest to crest—is measured in millionths of an inch; the waves set up by wireless oscillations may have a length of yards or even thousands of yards. The vibrations in the ether—whether they are the very short ones that we recognize as visible light, or the rather longer ones that we recognize as radiant heat, or the very much longer ones that we recognize as electro-magnetic waves—are exactly the same except as to their rate of vibration or "frequency". As their velocity or rate of travel is always the same—some 186,000 miles a second—whatever their length, it follows that the shorter the wave the higher the frequency. It is obvious that the longest light-waves, which are, roughly, one thirty-four thousandth part of an inch, must vibrate more quickly than a ten-foot wireless wave. The relative vibrations or frequencies are about four hundred billion a

second to about one hundred million a second.

Television involves the superposing of these appallingly high frequencies on the ordinary electro-magnetic carrier-waves used in wireless. The latter are easily controlled; the former are not. The problem turns as much as anything on the difficulty of loading an infinitely fine thing on to a relatively coarse thing. That practical progress has been made is the most certain indication that what is, at present, the novelty of "seeing-in" will in time become as much a commonplace as listening-in. The wireless transmission of *shadows*, that is to say, silhouettes, or black figures on a lighted background, is an established commercial possibility. M. Edouard Belin's system is one of the best known of these. The image to be transmitted is reflected by two vibrating mirrors so that, in a zigzag way, bit by bit, it is made to traverse a photo-electric cell. The current from this cell controls the fluctuations of an electric ray at the receiver, where it then traverses a fluorescent screen in a zigzag path which corresponds with the path taken by the image at the receiver. That, in fifty words or so, is what happens; and I believe it happens with a reasonable measure of success. But the synchronization of the mechanism for controlling the vibrations of the



The first successful model of the Baird "Televisor". Now in the Science Museum, South Kensington, London

By courtesy of Messrs. The Baird International Television, Ltd.

A COMPLETE "TELEVISOR"

A television receiver. It includes a loud speaker behind the grille on left and a viewing window on right

mirrors at the sending end and the zigzag passage of the cathode ray on the fluorescent screen at the receiving end are marvels of scientific exactitude altogether beyond me—and most other people.

Experts declare that to obtain recognizable reproduction of a picture, or a living image, the permissible error in synchronism must not exceed a factor which is equal to one part in ten thousand. If you consider for a moment the degree to which listening-in sets have been made sufficiently "fool-proof" for unscientific folk to handle and enjoy, and the extent to which they are mishandled and abused, I think you will agree that seeing-in presents a problem for inventors and manufacturers that bristles with difficulties. We have touched on some of them; but there are others, as, for example, the very broad "band" of wave-lengths—we may call it "ether-space"—required by a station transmitting living pictures. You must understand, first of all, that, before it can be transmitted, any picture, still or living, must be broken up into tiny fragments that become, in effect, the dots composing the mosaic of light of infinite graduations of intensity that give the high-lights, half-tones, shadows slight or heavy—just as a printed reproduction of a

photograph is broken up into minute dots by the process-blockmaker's screen.

To give a reasonable degree of fineness of detail a process-screen must have some 1600 dots to the square inch, that is, 230,400 dots to compose a picture one foot square. Easy enough, says the enthusiast, to energize electro-magnetically such a trifling number, each in its turn being caused to convey the light it reflects to a light-sensitive cell. Possibly. If the picture is a still one—a sketch or a photograph—we do not mind waiting several minutes while you transmit the 230,400 dots. But are we to be satisfied with studies in still life? True television seems to imply the transmission of living images and scenes; and into that enters a complication in the phenomenon known as persistence of vision. Our eyes retain an image for a tenth of a second before a fresh image can be telegraphed to the brain. Therefore any picture in which there is a change—any scene of movement, as of someone speaking or winking—must be shown to us at the rate of ten images a second, if we are to receive a clear impression of it. Our 230,400 dots must now be transmitted ten times a second, with the result that nearly two and a half million dots a second must be used to "modulate" a wireless wave.

So much for difficulties. Now let us notice what is being done towards their practical solution. First of all there is the Fultograph, operating Captain Otho Fulton's very ingenious and relatively simple system of wireless picture transmission. The apparatus is actually on sale in the wireless shops at a very moderate price, and the British Broadcasting Corporation provide regular facilities for transmission. The Fultograph will only transmit pictures on paper—portraits, sketches, cartoons, and so forth—so that it does not attempt true television; but within this limitation it is a practical success. The process is electro-chemical, the picture to be transmitted being made on a specially prepared paper. This paper is pasted on to the brass cylinder of an instrument that is first cousin to the phonograph. As the cylinder rotates it maintains contact with an electric needle or stylus which pricks out the pattern on the paper. The variations of the current react on the chemical in the paper and turn it sepia or leave it white, producing, by the time the stylus has completed its journey, a picture broken into millions of dots. Each dot contributes to the wireless carrier-wave a signal impulse which varies according to the degree to which the current reacted on the paper. The

receiver has a similar cylinder, driven by clockwork, on which is placed a sheet of specially sensitized paper. As the cylinder revolves the dots from the transmitter reappear, one by one, their density corresponding, of course, to the strength of the signal impulses, and so the picture is gradually traced before the eyes of those watching the receiver. The finished picture can be detached from the machine. It has rather the appearance of a fine sepia print.

Television in its true sense—the transmission of living scenes—has been successfully accomplished by John L. Baird, a Scottish electric engineer. Like other inventors, Baird was successful in transmitting shadows years before he was able to transmit actual objects, but by a perseverance that conquered, one after another, difficulties that had daunted many another inventor, he had in 1926 outstripped his competitors in other countries by demonstrating, for the first time in public, the wireless reproduction of animated scenes. All those who witnessed this demonstration were much impressed by the practical results attained. Mr. Baird's system was taken over for development by a company that has not stinted pains or money to make it a commercial success, and it is quite probable that before these lines are

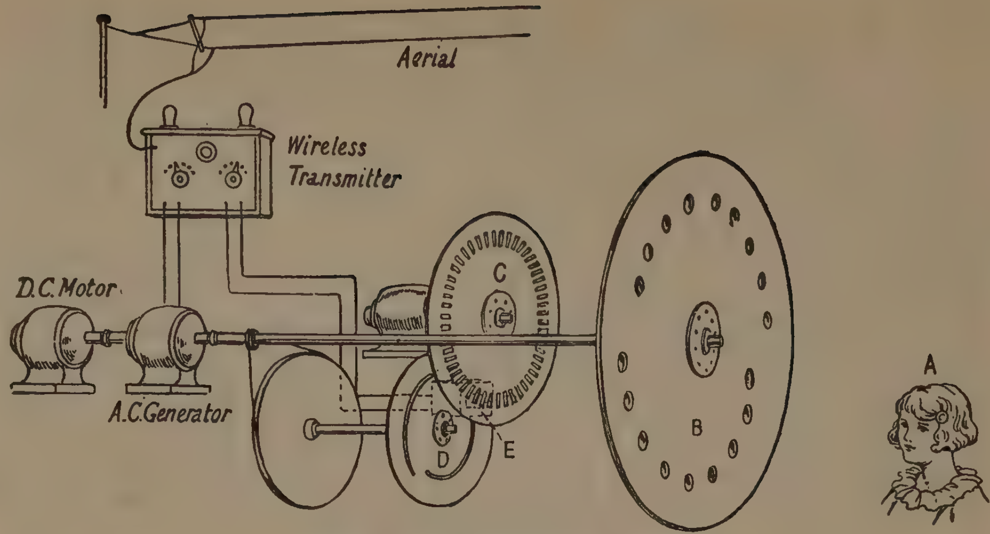


Diagram of Original Model of Baird Transmitter

A, Object to be transmitted. B, Revolving disc with lenses. C, Slotted disc revolving at high speed. D, Rotating spiral slot. E, The aperture through which the light passes to the light-sensitive cell.

printed my readers will have heard a great deal more about the Baird " Television ". They may even have " looked-in " to it.

The principle of the Baird system is very interesting. As in other systems, the subject to be transmitted is flooded with the most intense light that can be brought to bear upon it It is, of course, the light reflected by the image that must be turned into electric impulses for transmission, and Mr. Baird employs a lens for focusing this reflected light upon a particular type of photo-electric cell. What is specially interesting is his device for " exploring " or analysing the subject for transmission—for breaking it up into dots or tiny sections of varying brilliancy, each one of which must in turn influence the light-sensitive cell. This exploring device consists of revolving discs with perforations, interposed between the lens and the cell. The first disc has a large number of staggered apertures with lenses and revolves at about 800 revolutions a minute; being immediately in front of the object of transmission, it passes on to the next disc a succession of images of the object. This second disc has a great number of slots and revolves much more quickly—about 4000 revolutions a minute—its effect being to direct the light to the cell in

a series of very rapid flashes. The flashes have still to traverse a third revolving disc, with a spiral slot, which further subdivides the image.

The receiver is on a similar plan. The varying current coming into the aerial causes corresponding variations in the light from a neon-discharge lamp. This light is made to pass through rotating discs revolving exactly in step with those at the transmitter, the synchronism being maintained electrically from the transmitter. The spot of light from the lamp is thrown on to a small screen of ground glass, on which the picture is reconstructed. According to the intensity of the light-flashes at the transmitter, the current impulses vary the intensity of the light from the lamp in the receiver. Thus, the spot of light is bright at the high-lights and dim at the shadows. It traverses the screen so rapidly that, owing to persistence of vision, the whole image appears instantaneously to the eye.

Practical television may lag for a while in competition with established forms of indoor entertainment, but it is bound to become an accepted service to society. After all, it is but one of many marvels, some dimly sensed, some yet unthought of, that the Age of Wireless must bring to pass.

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